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Adaptive management of Ramsar wetlands

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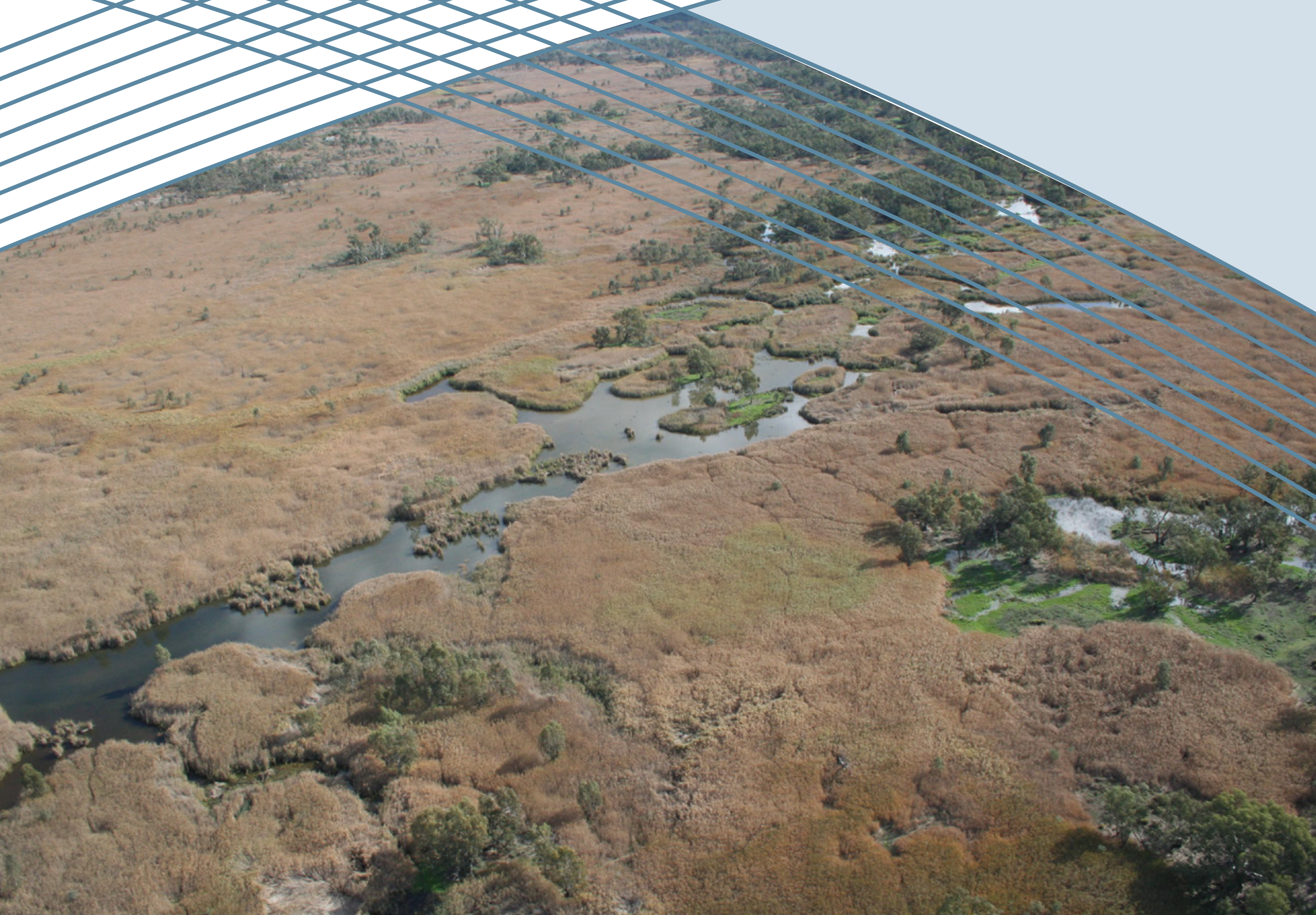

ADAPTIVE MANAGEMENT OF RAMSAR WETLANDS

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The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision-makers in government, business and in vulnerable sectors and communities to manage the risk of climate change impacts.

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ABSTRACT

The Macquarie Marshes are one of Australia's iconic wetlands, recognised for their international importance, providing habitat for some of the continent's more important waterbird breeding sites as well as complex and extensive flood-dependent vegetation communities. Part of the area is recognised as a wetland of international importance, under the Ramsar Convention. River regulation has affected their resilience, which may increase with climate change. Counteracting these impacts, the increased amount of environmental flow provided to the wetland through the buy-back and increased wildlife allocation have redressed some of the impacts of river regulation. This project assists in the development of an adaptive management framework for this Ramsar-listed wetland. It brings together current management and available science to provide an informed hierarchy of objectives that incorporates climate change adaptation and assists transparent management. The project adopts a generic approach allowing the framework to be transferred to other wetlands, including Ramsar-listed wetlands, supplied by rivers ranging from highly regulated to free flowing. The integration of management with science allows key indicators to be monitored that will inform management and promote increasingly informed decisions. The project involved a multi-disciplinary team of scientists and managers working on one of the more difficult challenges for Australia, exacerbated by increasing impacts of climate change on flows and inundation patterns.

EXECUTIVE SUMMARY

This project applies an adaptive management planning approach to address climate change adaptation strategies in internationally significant wetlands (Ramsar-listed), focussing on the Macquarie Marshes as a case study. This project aims to provide information, knowledge, and models underpinning adaptive management planning, and integrate climate change adaptation plans across spatial and jurisdictional scales to promote ecosystem resilience and sustainable water resource management. With drying associated with overexploitation of water resources and climate change, many freshwater plant and animal species and functions in the Macquarie Marshes are close to limits of tolerance and in decline. With climate change exacerbating these stresses, through decreases in flow and increases in temperature, thresholds of change need to be resolved to identify management options for conserving freshwater species and ecosystems that may be near their climate limits. The Macquarie Marshes are an excellent example of a system sensitive to hydrological processes across multiple scales.

This project aimed to consolidate and add scientific knowledge required for the adaptive management of the Macquarie Marshes. Specifically, we aimed to integrate climate change adaptation strategies across different management scales and responsibilities. The project consisted of four main objectives.

1) To provide scientific and stakeholder information underpinning adaptive management planning for climate change in the case study of a wetland of international importance - the Macquarie Marshes;
2) To incorporate climate change adaptation into a hierarchy of objectives for management;
3) To develop a process model, scientific management thresholds and targets for rehabilitation for key organisms and ecological processes in adapting to climate change and;
4) To identify opportunities to integrate different planning processes and incorporate effects of climate change on conservation goals.

Following the framework for strategic adaptive management, this project involved six key activities and interacted and added to the four main steps of the generic management framework:

1) Review and collate scientific information

Ecological datasets are a critical component for establishing robust ecological response models for ecosystem management and climate change projections. We compiled all available datasets of both ecological components of the ecosystem as well as potential drivers of change (i.e., inundation and fire history). We defined three broad categories: boundaries, drivers, and ecology (representing ecosystem responses). Where available, data included both temporal and spatial coverage. Subsequently, compiled databases formed the basis for developing an information platform for the Macquarie Marshes (section 3.5), modelling responses of key ecological assets, and developing a comprehensive process model of the ecosystem (section 3.3) to assist in identifying climate-change adaptation opportunities.

2) Climate change and hierarchy of objectives

Climate change adaptation requires complex decision-making processes for the near and more distant future taking into account environmental and climatic change. Structured decision-making can provide insightful ways to help address the complexities involved with identifying and prioritising key conservation values as well

as choosing among alternative management strategies. Understanding these linkages through the formation of an objectives hierarchy is crucial for informed and transparent decision-making and integration, within an adaptive management framework. We aimed to identify and incorporate climate adaptation objectives into the hierarchy of objectives for the management of the Macquarie Marshes Nature Reserve. At present, significant work has been done in development of a hierarchy of objectives with Office of Environment and Heritage (NSW), detailing high-level objectives. Presently, an explicit consideration of climate change adaptation strategies, within the developed objectives hierarchy, is lacking.

Loss of flooding due to river regulation is the key degrading factor in the declining resilience of the Macquarie Marshes wetland ecosystem, driving both ecological and social systems beyond viable thresholds, significantly increasing susceptibility to the impacts of climate change. As summarised (3.2.3), climate change in the Macquarie Marshes will probably primarily drive reduction in flooding volumes and frequencies. However, past impacts of water regulation on loss of flooding will likely continue to overshadow those projected through climate change. Given existing water entitlements to the Macquarie Marshes (146243ML general security and 3340ML supplementary), the likelihood of resilience to anticipated climate change is uncertain. The single primary adaptation for restoring the Macquarie Marshes ecosystem is the return of adequate environmental water needed to restore the short and moderate inter-flood intervals. This can be achieved through increased water entitlements for the environment or reductions in extractive share of flow through changes in legislation and policy.

Potential adaptations may include:

- Water Flows: obtaining adequate environmental water to restore the short and moderate inter flood intervals;
- On-ground Management: improving the management and use of existing water allocations as well as to maximise the effectiveness of treatment and abatement activities;
- Social values: promoting and increasing social understanding within the local and broader community of the value of the natural environment of the Macquarie Marshes;
- Water Sharing Plan: reviewing the water sharing plan to specify shorter durations for the inter flood intervals;
- Modelling Capacity: improving regional scale modelling capacity of climate change projections that enable maximising ecological returns on environmental flows; and
- Strategic Adaptive Management: implementing a strategic adaptive management with appropriate documentation that can be reviewed and used for decision-making.

Within the context of structured decision-making, climate change adaptation strategies should be linked to three of the four high level objectives identified for the Macquarie Marshes. Adaptation of water flows is achieved through management as well as policy and therefore should link both to ecosystem objectives under the management of environmental water for key ecological objectives as well as to the enabling objectives aimed to effectively engage with water management policies, planning, and processes to support functioning ecosystems. Adaptation through amendments to the water-sharing plan should also be lined under similar enabling and water sharing objectives. Promoting social understanding should link under the high-level people’s objectives, focusing on building partnerships with local farmers and communities. Increasing modelling capacity can only be attained through the support of science under enabling objectives. Finally, the implementation of a strategic adaptive management plan falls naturally under the wetlands adaptive management strategy objectives within the high-level enabling objective.

3) Process model of the ecosystem

A critical component for improving adaptation for freshwater ecosystems, within the adaptive management framework, is to build a common understanding of system behaviour through a developed process model. Here we identified different wetland states and potential drivers related to water availability and climate change using two approaches. The first approach taken (3.3.1) relied on expect knowledge accumulated over many years with both management experience and scientific knowledge of in the Macquarie Marshes system, elicited through a dedicated workshop. Workshop outcomes sketch a coarse decision analysis for a complex problem. While the analysis provides context for how predictive models can be utilised in decision-making, the primary goal of the workshop was elicitation of plausible models of cause and effect. These outcomes form a sound basis for extending, and formalising models to inform future management. The attributes point to logical priorities for monitoring outcomes, although the actual variables monitored are likely to require further refinement when costs, feasibility, and other assets of concern are fully considered.

The second approach (3.3.2 and 3.3.3) also employed a process model but built on data-driven statistical models to examine the response of two key indicators of the Macquarie Marshes to inundation and flow patterns. As the first indicator (3.3.2), we explored alternative water management strategies and identified maximal strategies for successful long-term management of colonial waterbirds. We modelled fluctuations in breeding abundances of ten colonial waterbird species over the past quarter-century (1986-2010). We examined the effects of five environmental flow management strategies on the variability of flows and subsequent likelihood of breeding. Clear relationships existed between flows and breeding, both in frequencies and total abundances, with a strong linear relationship for flows >200GL. Thresholds emerged for triggering breeding events in all ten species, but these varied among species. Three species displayed a sharp threshold response between 100-250GL. These had a breeding probability of 0.5 when flows were >180GL and a 0.9 probability of breeding with flows >350GL. The remaining species had a probability greater than 0.5 of breeding when flows >400GL. Management to different target volumes of environmental flows affected overall and specific breeding probabilities. The likelihood of breeding for all ten colonial waterbirds increased from a regulated historical average of 0.36±0.09SD to 0.53±0.14SD, an improvement of 47.5%±18.7SD.

As the second indicators (3.3.2), we developed a quantitative state and transition models with probabilities for key vegetation communities. We developed a predictive capacity linking transition and persistence of vegetation communities to varying water allocations. We found significant transitions of vegetation communities between 1991 and 2008. Overall, vegetation communities became increasingly drier. Terrestrial extent increased by 38%, largely at the expense of Semi-permanent wetland and open-water extent, which decreased by 21% and 73%, respectively. The extent of floodplain vegetation remained largely unchanged. Terrestrial communities had the highest probability of persisting (pp=0.978±0.002SD) and the lowest probability of inundation (p=0.082±0.132SD). Floodplain vegetation communities remained very stable, with persistence probability of p=0.971±0.002SD and ample likelihood of inundation (p=0.437±0.289), (Table 1). Floodplain vegetation communities that experienced higher probability of inundation (p=0.767±0.128) transitioned to Semi-permanent wetland communities (p=0.016±0.002). Semi-permanent wetland communities had a lower probability of persistence and a significant likelihood of transitioning to terrestrial communities (Table 1). Explicitly, cells that experienced lower inundation probabilities (p=0.252±0.179SD) were more likely to transition to terrestrial communities (p=0.505±0.007), while cells with higher inundation probabilities (p=0.676±0.166SD) were more likely to persist (p=0.455±0.007). Model selection identified probability for inundation between the two vegetation surveys (1991 and 2007) and distance to nearest stream as the best model of state transition probabilities. Identified model was then used to predicted persistence probabilities across the Macquarie Marshes. Spatially, the most significant changes in transition probabilities occurred in the southern parts of the Macquarie Marshes nature reserve.

Finally, we integrated developed statistical models to form a cohesive process models for the ecosystem (3.3.4). We incorporated modelled ecological responses of colonial waterbird breeding, vegetation communities' persistence probability, frogs abundance, epicormic growth of river red gums, and invertebrates abundance with total spring flow volumes to form a comprehensive process model of the Macquarie Marshes ecosystem. Framing these models within a Bayesian Belief Network, enables estimating the likelihood of the state of a parameter (e.g., breeding), given the states of input parameters such as total annual spring flow and climate change.

4) Policy and legalisation

Many different legislative and policy frameworks interact and focus on management of wetlands, particularly wetlands of international importance and their water supply (i.e. rivers) within a catchment context. There is a strong commitment by many governments to implementing adaptive management but this can be difficult given there are policies and legislative processes already in place which are the 'operating space' for environmental management. We discuss policy and legislation implications of a strategic adaptive management framework for the Macquarie Marshes. Specifically, we identify alignment of the adaptive management approach with current policies and processes and the potential for integration of these policies and planning structures into a cohesive SAM framework at different government and spatial scales. All relevant legislation and governance frameworks were considered: State, Commonwealth, and international levels. We particularly focused on recent changes to the governance of the Murray-Darling Basin, implemented through the Water Act 2007 and its instrument the Murray-Darling Basin Plan, which usher in a new era of water policy that aims to rehabilitate the basin's ecosystems and address overexploitation and mismanagement of water resources. We begin with background information on the Macquarie Marshes and their ecological significance and then briefly review the governance framework for water policy in the Murray-Darling Basin. Integration of legislation, policy, and processes into the strategic adaptive management framework. There are a range of different responsibilities for policy and management of the Macquarie Marshes with different organisations. A strategic adaptive management approach could unify and integrate these different responsibilities, to deliver on a common purpose. The major factor determining the ecological health of the Macquarie Marshes is the amount of environmental water flowing into the marshes, combined with the natural flow regime, determining how much and when this water is released. A strategic adaptive management framework could help build on the established process, providing clear links between different aspects of environmental flow management including how this links with to terrestrial aspects of the Macquarie Marshes and its management. The most significant challenge for establishment of a strategic adaptive management framework for the Macquarie Marshes is the willingness of different agencies to embark on this journey. It requires investment in joint development of a vision and hierarchy of objectives, which can drive management, monitoring and reporting. The current responsibilities of different agencies can be incorporated within a strategic adaptive management framework but it does require a level of coordination, which would be challenging. This does not mean it would need to be established immediately. It could be treated as a journey. Many of the critical elements for a strategic adaptive management framework and its implementation are already well established for the Macquarie Marshes.

5) Adaptive Management Information Tool (AMIT)

A critical constraint on management in general and devising adaptation strategies in particular is availability and access to scientific information. When available, high quality datasets can support decision-making and communication of relevant information to stakeholders. With better information and accessibility, better decisions can be made. Consolidating multiple datasets where data are accessible through a single point of entry carries several key advantages. A single dataset ensures data can be constantly updated and expanded to encompass all available data. Sharing of information is significantly more effectual in terms of resource use and can strengthen communication with the public on management outcomes. Importantly, key indicators can be jointly developed and used to provide a better understanding of response to environmental variation or managerial actions. These returns support better decision-making and guide future strategies of adaptation. Critical to adaptive management, robust data forms the basis on which management can evaluate its actions and form the basis for more efficient strategies required to achieve desired outcomes. We developed an information platform that calls up data on biota, ecological processes, and modelling into a spatiotemporal interface. Use of data allows access to key scientific information and modelling for climate adaptation and management. This interface focuses on the response of flood dependant ecosystem processes to determine adaptation opportunities delivered with climate adaptation to altered flow regimes (e.g. environmental flow management) based on modelling approaches undertaken in this report and within the Australian Wetlands, Rivers, and Landscapes Centre.

6) Review local knowledge

We focussed on documenting the local knowledge that graziers and government employees have gained from living and/or working in the Macquarie Marshes through the boom and bust cycles that characterize arid-zone rivers and wetlands. We sought to record the ecological observations of graziers and government employees over decadal time scales across periods of drought, flood, and changes in river management. We also wanted to understand how graziers might adapt to increased temperatures, reduced flooding, and more frequent drought as predicted with climate change. Landholders on the Macquarie Marshes have experienced extremes in these three variables and we are interested in their observations and strategies used under these conditions. We were interested in whether these practices may also help adapt to the possible consequences of climate change.

We collected information to help develop and evaluate climate change adaptation for floodplain wetlands and manage water for irrigation and the environment. These interviews also served to help identify management strategies that can be studied further in future research. In particular, climate change adaptation strategies involve complex trade-offs between the values different stakeholders associate with the ecosystem goods and services provided by floodplains and their wetlands. Climate change exacerbates the uncertainty associated with evaluating these trade-offs. By recording local knowledge, we will ensure that these valuable memories of past and present events can be utilized in river and climate change planning. We asked participants for demographic information, and for information about their local knowledge of past and present events. Participants were asked about their farming practices and their adaptation strategies to deal with projected climate change.

A number of patterns emerged from the interviews of changes observed by landholders in the occurrence of animals across time. These included a decline in both high numbers of mosquitoes from the 1970s and black butterflies from the 1980s until the flooding in 2010. Dragonflies have not been observed in high numbers since the late 1980s. The pattern is similar for snakes and frogs which were observed to decline in the 1980s, but started to improve 30 years later in the 2010 flooding. In contrast turtles appear less abundant now, possibly due to predation on their eggs by feral cats and foxes. Waterbird breeding was observed to decline from the 1980s, but swans were abundant on lagoons around 2000. The bustard is no longer seen in the Marshes. Cod, catfish and yellow belly were prevalent until the mid-1970s, but declines in the mid-1980s coinciding with the arrival of carp and gambusia. In terms of plants, the main changes observed were the loss of reeds in the 1980s and their re-appearance in some parts in the recent wet years. Wetland plants were observed to persist, but less often due to reduced flooding.

Landholders observed that water is moving through the system faster than in the past and thought this was due to dry conditions and loss of vegetation cover. Associated with this was a perception that erosion is increasing. They observed good water quality generally, without any issues such as blackwater and blue-green algae. Many landholders could identify the source of floodwater based on its colour.

Conclusion

This project aimed to consolidate and add scientific knowledge required for the adaptive management of the Macquarie Marshes. Specifically, we aimed to integrate climate change adaptation strategies across different management scales and responsibilities. Adaptation strategies are vital, as climate change will inevitably affect conservation objectives, policies, and legislation, all of which will influence the availability of water, the key ecological driver of the system. Following the framework for strategic adaptive management, this project interacted and added to the four main steps of the generic adaptive management framework.

Both review of scientific information (3.1) and review of local knowledge (3.6) provided valuable data required for developing management objectives, thresholds for the ecosystem, and responses to drivers, including climate change. These helped clarify and reinforced the key attributes of the ecosystem (biophysical, cultural, and services) that characterised the intrinsic nature of the Macquarie Marshes. Recording long-term local knowledge information of past flooding patterns and responses of biota can significantly improve our conceptual models of how the system works and how it will respond to projected climate changes. Once recognized, key attributes then form the basis for establishing management objectives.

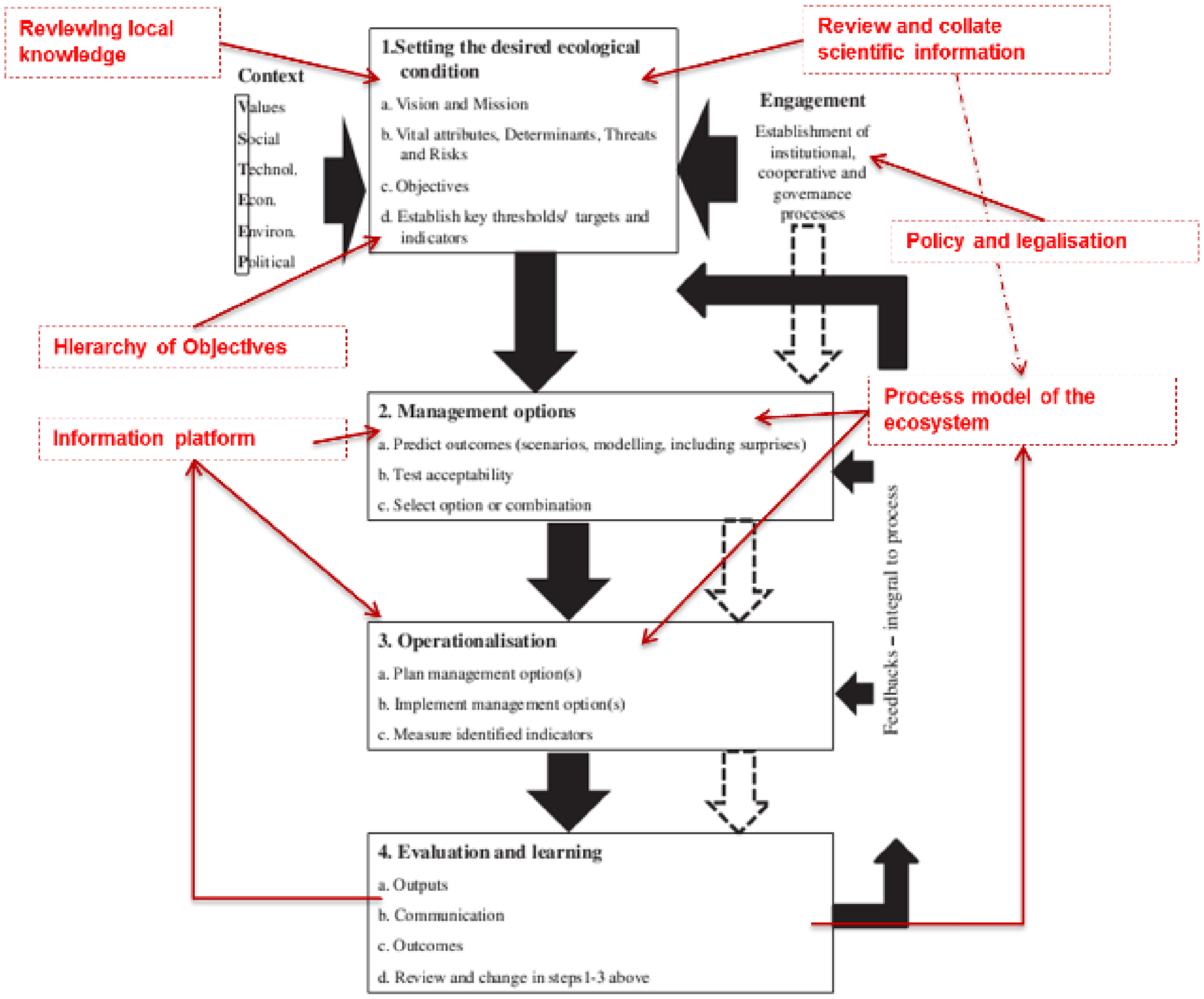
This project further integrated climate change adaptation objectives within the adaptive management framework, as part of the objectives hierarchy (3.2), currently under development within the NSW Office of Environment and Heritage. This project provides opportunities for identifying how climate change adaptation strategies may be incorporated within an objectives hierarchy. In many ways, incorporation of climate change objectives within this hierarchy is simply an extension of how objectives and processes are established to deal with the effects of water resource development on the ecosystem. True adaptation to climate change will require coordinated institutional and policy change which may be effected through the SAM approach.

Critically, SAM depends on constraints and opportunities, which can be provided by legislation and policy as well as drivers in ecosystems. Many different policies and legislative instruments affect the management of wetland ecosystems, operating at different spatial scales, reflecting different institutions and their focus. These policies and legislative responsibilities operate at different levels but are particularly important in determining the achievability of objectives. It is clear that despite the many different policies and legislative instruments governing the Macquarie Marshes and its water management, the development of a SAM approach is consistent across all types of legislation. Thus, governance, planning and policy driven by the different legislative planning requires assessment of alignment to further drive the proposed climate adaptation approach. This project reviews, details objective settings, and legislative responsibilities. More so, the project assesses alignment with the adaptive management framework and identifies opportunities to incorporate climate adaptation into existing management plans (3.4). There was considerable opportunity to develop and build on the current progress by OEH in the SAM approach in the Macquarie Marshes, providing a more integrated and effective way of managing the different legislative and institutional responsibilities affecting the management of the Macquarie Marshes.

Understanding how a system works and the impacts of drivers on stressors and ecosystem responses remains a critical step, allowing for improved predictions from modelling. Building a system model of the ecosystem is critical as it facilitates testing alternative management options against our understanding of the ecosystem. Providing an explicit model should include key components of the ecosystem. This project developed a quantitative process model detailing the different ecological states and the main drivers of change (3.3). The complexity of the process model was highly dependable on the availability of ecological and physical information. Continuous and long term monitoring of two key attributes of the Macquarie Marshes (i.e., colonial waterbird breeding and vegetation communities) along with corresponding flow and inundation patterns enabled the development of a relatively robust process model for the ecosystem. As exemplified here, developing such a model is critical in realising opportunities for adaptation and prediction for management of the Macquarie Marshes within the framework. .

A critical constraint on adaptation is access to scientific information for adaptation management. This project also developed an information platform that could assist managers (and the public) in calling up of data on biota, ecological processes, and a modelling capacity into a spatiotemporal interface (3.5). Providing an information platform amassing all available information relating the system can significantly improve evaluation and learning, a critical component of adaptive management. For adaptive management to succeed, management practices require constant feedback loops from data to planning. As more information is gathered and incorporated into the information platform, models and past decisions can be reviewed, adapted, and optimised for delivering greater certainty in achieving desired management outcomes.

Integration of project outcomes within the strategic adaptive management framework



1. INTRODUCTION

The management of water resources and dependent ecosystems remains one of the most critical issues for Australia (Kingsford, 2000), exacerbated by increasing impacts of climate change (rainfall reductions, increased variability, increased temperatures and increased evaporation), affecting many freshwater ecosystems (Pittock and Finlayson, 2011, Junk et al., 2012). This is requiring new ways of management with explicit identification of objectives for long-term conservation (Kingsford, 2011). Currently, management of freshwater species and ecosystems seldom incorporates specific climate change adaptation to promote their resilience. For example, the Murray-Darling Basin Plan acknowledges climate change challenges, but does not propose any particular adaptations, apart from alteration of water sharing plans in the review cycles (MDBA, 2012a). The pressures confronting management of water resources are particularly significant for freshwater ecosystems in this basin, exemplified by the Macquarie Marshes (Thomas et al., 2011a). This is a wetland of international significance (Ramsar-listed), also important for migratory birds (another international responsibility), and one of only three Australian freshwater ecosystems where the international community has been formally informed of the likelihood of a detrimental change in ecological character, resulting from anthropogenic impacts. There is considerable potential to improve current management that maximises mitigation measures, including the delivery of environmental flows, protection of core refugia and conservation of free-flowing rivers (i.e.Talbragar River) through adaptive management.

1.1. Project background

This project builds on an implementation framework for management of a wetland of high conservation value (Kingsford et al., 2011a), focused on the Macquarie Marshes. We aimed to integrate climate change adaptation strategies across different management scales and responsibilities and develop a climate adaptation capacity within this generic management framework (Kingsford et al., 2011a). The framework integrates across different management scales and responsibilities: wetland, river, basin, jurisdictional, national, and international. Following the framework for strategic adaptive management (Kingsford et al. 2011), this project involved six key activities and interacted and added to the four main steps of the generic management framework. Principally, the project links management for freshwater conservation through scientific tools, including process models, and data that support adaptive measures that promote resilience to climate change. Resilience defines how much disturbance an ecological can absorb without moving to a different state, including a shift in the functional groups of organisms and processes and the ability to recover (Gunderson, 2000). These linkages are challenging, because knowledge is dispersed and uncertain and there is not a well-constructed framework for integration of science into management. Despite much lauded strengths and benefits, adaptive management has rarely been implemented successfully at an institutional level (Keith et al., 2011).

This project builds on the NSW Office of Environment and Heritage (OEH) commitment and early progress to develop an adaptive management framework within the Macquarie Marshes (OEH, 2012). The project has continued to develop links between practical management objectives to scientifically derived thresholds of resilience for key freshwater biota potentially affected by climate change. A critical step involved building a common understanding of system behaviour by developing a process model to identify different wetland states and the potential drivers related to climate change. Such mechanistic knowledge, with data on indicators, is critical in realising opportunities for improved adaptation for freshwater ecosystems, within the management framework. Governance, planning and policy driven by the different legislative planning require assessment of alignment to further drive the proposed climate adaptation approach.

In addition, we reviewed and detailed objective setting and legislative responsibilities to assess alignment with adaptive management approach and opportunities to incorporate climate adaptation into management. These included:

1. The Water Sharing Plan (Water Management Act 2000),
2. Protected Area Plan of Management (National Parks and Wildlife Act 1974) and environmental flow management
3. Threat abatement planning (Threatened Species Conservation Act 1995),
4. Catchment Action Plan (Catchment Management Authorities Act 2003),
5. The Murray-Darling Basin Plan and Water Act 2007 and
6. The Environmental Water Holder operations plan (Environment Protection and Biodiversity Conservation Act 1999, Water Act 2007).

We also interviewed different landholders living and deriving their income from the flooding of the Macquarie Marshes. They have long experience of changes delivered by water resource development upstream as well as potential impacts of climate change on their rearing of livestock on the floodplain of the Macquarie Marshes.

1.2. Adaptive management

This project applies a widely applicable, but rarely implemented, adaptive management planning approach to address climate change adaptation strategies in internationally significant wetlands (Ramsar-listed), focussing on the Macquarie Marshes as a case study. This project aimed to provide the scientific foundations underpinning adaptive management planning (Kingsford et al., 2011a), and integrate climate change adaptation plans across spatial and jurisdictional scales to promote ecosystem resilience and sustainable water resource management.

With drying associated with overexploitation of water resources and climate change, many freshwater plant and animal species and functions in the Macquarie Marshes are close to limits of tolerance and in decline (Kingsford and Thomas, 1995, Herron et al., 2002, Ren et al., 2010, Ren and Kingsford, 2011). With climate change exacerbating these stresses, through decreases in flow and increases in temperature (Parry et al., 2007, CSIRO, 2008c), thresholds of change need to be resolved to identify management options for conserving freshwater species and ecosystems that may be near their climate limits.

The Macquarie Marshes are an excellent example of a system sensitive to hydrological processes across multiple scales (Ren et al., 2010). For the Macquarie Marshes, climate change is predicted to affect conservation goals, policies, and programs, including international obligations, influencing the availability of water, the key ecological driver of the system (Herron et al., 2002, CSIRO, 2008a). Existing planning instruments variously reflect different conservation and water management policies and goals (e.g. Murray-Darling Basin Plan, Water Sharing Plan, Plan of management for Nature Reserve, Catchment Action Plan, Environmental Water Holder Watering Plan, floodplain management plan). Generally, these poorly integrate ecological resilience, flow management in the face of climate change through the landscape, despite similar goals to support conservation of wetlands. Further, climate adaptation is currently poorly incorporated in any plans at local, landscape, catchment, or regional scales. The Murray-Darling Basin Plan (MDBA, 2012a) has explicit objectives to improve ecosystem resilience to climate change and other risks but these need to be incorporated within the current water shares. The Murray-Darling Basin Plan stipulates that a water resource plan must consider alternative management of water in case climate change alters the likelihood of extreme events. However, there is no explicit adjustment mechanism for reducing impacts of climate change on ecosystems.

The key focus of this project, a climate adaptation plan for the Macquarie Marshes, aimed to interact with management of water resources in the agricultural sector, regional urban sector and recreation and tourism sectors, all dependent on water for sustainability. The project also aimed to assist in the development of an adaptive management plan, (underway within the New South Wales environment agency, OEH), incorporating climate change. Conservation of the Macquarie Marshes ecosystem could benefit from water management technologies, efficiencies, and trading in these other sectors, some of which were identified in an NCCARF synthesis project (Jenkins et al., 2011). Through extension of adaptive management, incorporating local knowledge, the proposed adaptation plan will integrate cross-sectoral processes to maximise the benefits for this internationally renowned ecosystem. In particular, this project built on a completed NCCARF synthesis project, which identified climate adaptation opportunities from managers and other sectors. These opportunities could be incorporated into adaptive management planning (Jenkins et al., 2011). For example, the two highest ranked adaptations identified in a recent stakeholder workshop, indicated willingness to develop responsive adaptive management. Although the synthesis project revealed gaps in policy instruments and adaptation limits with local land managers, it did not provide mechanisms for implementation, the focus of this project.

2. OBJECTIVES AND RESEARCH APPROACH

This project aimed to consolidate and add scientific knowledge required for the adaptive management of the Macquarie Marshes. Specifically, we aimed to integrate climate change adaptation strategies across different management scales and responsibilities. The project consisted of four main objectives: 1) To provide scientific and stakeholder information underpinning adaptive management planning for climate change in the case study of a wetland of international importance - the Macquarie Marshes; 2) To incorporate climate change adaptation into a hierarchy of objectives for management; 3) To develop a process model, scientific management thresholds and targets for rehabilitation for key organisms and ecological processes in adapting to climate change and; 4) To identify opportunities to integrate different planning processes and incorporate effects of climate change on conservation goals. Following the framework for strategic adaptive management (Kingsford et al. 2011), this project involved six key activities and interacted and added to the four main steps of the generic management framework (see section 6.1, Figure 59). Detailed methods for each activity are provided within the results and outputs of each section.

2.1. Review and collate scientific information

We aimed to further review and collate available scientific information (published and data sets), underpinning development of management objectives and thresholds for the aquatic ecosystem, its biota and responses to drivers, including climate change. There is considerable scientific information relevant to the aquatic biota and ecosystem processes of the Macquarie Marshes but no consolidation or access that can be used for climate adaptation and management. The recent synthesis (Aldous et al., 2011) broadly identified potential impacts of changing climate and potential adaptation measures available for the wetlands in the Murray-Darling Basin but did not investigate availability and accessibility of data or information on all biota in decline, critical for reporting on management effectiveness. This objective could be achieved through building on our recent detailed literature review (Jenkins et al., 2011), analysis of the content of all databases to produce a metadata database of available data, including temporal and spatial coverage.

2.2. Climate change and the hierarchy of objectives

We aimed to identify and incorporate climate adaptation objectives into the hierarchy of objectives for the management of the Macquarie Marshes Nature Reserve. OEH is currently developing an adaptive management plan with a hierarchy of objectives, following identification of key attributes to be managed (e.g. river red gum, waterbirds and their breeding) and their dependency on factors amenable to management. The synthesis project (Jenkins et al., 2011) identified a need to extend this to include adaptation to climate change. Our project aimed to produce a framework for scientific information necessary for developing objectives and informing decision-making of management and provide the actual data, where available.

2.3. Process model of the ecosystem

We aimed to produce a process model of the ecosystem, and identify thresholds of concern and rehabilitation targets for key biota (e.g. waterbirds, vegetation). We focused on a model of ecosystem dynamics and identification of key transitions that influence resilience. This was done through a facilitated workshop, involving managers and scientists familiar with the system. The second part of this objective involved estimation of thresholds of adaptation for different biota and processes, based on key attributes identified by managers (e.g. river red gums, breeding of colonial waterbirds). This was done using the consolidated dataset (4.1). The aim was to explore thresholds of concern that may trigger management action, based on data. For this we developed model of ecological responses to inundation, flow and rainfall, allowing management scenario development for different flows and previously developed inundation models (Ren et al., 2010).

2.4. Policy and legalisation

We aimed to identify how climate change affects different policies, goals, and international obligations and integrate these into a cohesive adaptive management plan for the Macquarie Marshes. This part of the project examined all relevant legislation and planning policies and their conservation goals at the range of different scales (wetland, catchment, basin, jurisdictional, national, and international) to identify alignment, potential conflicts, and opportunity for incorporating climate change adaptation policies into the adaptive management framework. Plans included water management plans, operating plans of the Environmental Flows Reference Group, catchment action plans, Murray-Darling Basin Plan, environmental flow delivery plans, management plan for the Nature Reserve and the Ramsar site. Some background for adaptive management was developed for the Macquarie Marshes Nature Reserve (Kingsford et al., 2011a) but this provided limited detail for operational management within OEH (DECCW, 2010a).

2.5. Information platform

We developed a prototype Adaptive Management Information Tool (AMIT), allowing access to key scientific information, and modelling for climate adaptation and management. A critical constraint on adaptation is access to scientific information for adaptation management. This project developed a system that called up data on biota, ecological processes, and modelling into a spatiotemporal interface. This interface also included the distribution of flood dependent vegetation communities and their required flooding regimes to determine adaptation opportunities delivered with climate adaptation to altered flow regimes (e.g. environmental flow management) based on modelling capacity developed by the Australian Wetlands, Rivers and Landscapes Centre (AWRLC)(Ren et al., 2010)

2.6. Review local knowledge

We assembled expert local knowledge from different sectors (e.g. agricultural) for development of objectives and thresholds. This assisted with the development of potential climate adaptation measures for freshwater biodiversity conservation. Much of the Macquarie Marshes is on private land in which landholders rely on regular inundation to increase their capacity to sustain livestock. We investigated opportunities for synergies in climate adaptation; this can potentially tie into future management of their Marsh holdings. To underpin this information, local knowledge of flooding patterns and understanding of responses of biota from long-term residents was captured to produce an oral history of the Macquarie Marshes and the river.

2.7. Steering Committee

Given the complexity of this project, we formed a steering committee from all the major agencies involved in land and water management for conservation (Table 1). Represented agencies included National Parks and Wildlife, NSW Office of Environment and Heritage Policy, environmental flow management to Macquarie Marshes, Murray-Darling Basin Authority, NSW Office of Water, and Commonwealth Environmental Water Holder and Central West Catchment Management Authority. During the course of the project, we periodically met with steering committee members.

Members provided useful advice on direction and reviewed key documents produced from this project.

Table 1: Steering Committee members

Member's name	Affiliation
Louise Armstrong	Northern Basin Delivery, Commonwealth Environmental Water Office
Olivia Bush	Environmental Water Delivery, Commonwealth Environmental Water Office
Nick Cook	Team Leader Water Sharing Plan Science & Evaluation - North, NSW Department of Primary Industries - Office of Water
Rob Smith, Mark Fosdik and John Whittall	National Parks and Wildlife, Office of Environment and Heritage
Bill Johnson	Director, Environmental Watering Plan Implementation, Environmental Management Division, Murray–Darling Basin Authority
Debbie Love	Senior Wetlands and Rivers Conservation Officer - Macquarie, Regional Operations Group, Office of Environment and Heritage
Damian Lucas	Policy, Water & Wetlands Strategy, Office of Environment and Heritage
Steve Pearson	Coordinator - Policy & Investment, Central West CMA
Jen Shearing, Shona Whitfield, and Tracey MacDonald	Catchment Coordinator (Strategic Partnerships), Central West CMA

3. RESULTS AND OUTPUTS

3.1. Review and collate scientific information

Relevant scientific information needed for developing management objectives for the Macquarie Marshes resides as published material (reports and peer-reviewed literature), supported by data sets, as well as unpublished datasets. Considerable documentation has been compiled within the Water Information System for the Environment (WISE). The online database provided access to water related ecological information for the entire Macquarie-Castlereagh catchment, up to the mid-2000s. With relevance to this project, WISE offered access to spatially explicit publications, underpinned by their relevant data sets. Review of literature of related to impacts of climate change and adaptation strategies has been carried out as part of an early NCCARF synthesis project (Jenkins et al., 2011).

Ecological datasets are a critical component in any attempt at modelling for climate adaptation and ecosystem management. We defined three broad categories: boundaries, drivers, and ecology (representing ecosystem responses) (Table 2). We compiled all available datasets of both ecological components of the ecosystem as well as potential drivers of change (i.e., inundation and fire history) (Table 2). Where available, data included both temporal and spatial coverage. Subsequently, compiled databases formed the basis for developing an information platform for the Macquarie Marshes (see 3.5). Compiled databases, developed data platform, and modelling undertaking (see 3.3) would facilitate determining climate-change adaptation opportunities. Our review was also used to guide integration of climate adaptation into the hierarchy of objectives for the management of the Macquarie Marshes Nature Reserve (see 3.2). Much of the data remain poorly documented and require further resources for systematic compilation, storage, and access. This project focused on ensuring that the preliminary elements of data availability, access, and storage were incorporated into developed data platform.

Table 2: Collated Datasets for three broad categories for the Macquarie Marshes (boundaries, drivers, ecology) of data sets. Some were used for the prototype information platform (AMIT-Adaptive Management Information Tool)

Name	Group	Type
NSW Estate	NSW Estate	Boundary
Ramsar	RAMSAR	Boundary
Quambone	Aerial Images	Boundary
Walgett	Aerial Images	Boundary
RFS	Aerial Images	Boundary
Walgett & Wyngan	Aerial Images	Boundary
Landsat	Landsat	Boundary
LIDAR	LIDAR	Boundary
Flow volume	Hydrology	Driver
Inundation mapping	Hydrology	Driver
Fire history	Fire	Driver
Undefined in-stream structures	Structures	Driver
Channels	Structures	Driver
Levees	Structures	Driver
Off river storage	Structures	Driver
Tank	Structures	Driver
Uncertain earthworks	Structures	Driver
Rivers	Water bodies	Driver
Colonial Waterbird breeding	Birds	Ecology
Woodland Birds	Birds	Ecology
Aerial Survey of waterbirds	Birds	Ecology
NSW Atlas[1]	Fauna	Ecology
Historical fish data	Fish	Ecology
Invertebrate density	Invertebrate	Ecology
VegSurvey1949	Vegetation	Ecology
VegSurvey1963	Vegetation	Ecology
VegSurvey1981	Vegetation	Ecology
VegSurvey1991	Vegetation	Ecology
VegSurvey2008	Vegetation	Ecology
River Red Gums plots	Vegetation	Ecology
YETI	Vegetation	Ecology

[1]NSW contains records of plants, mammals, birds, reptiles, amphibians, some fish, and some (mainly endangered) invertebrates (OEH, 2012a)

Table 3: Data sets of value currently in development for use in the information platform.

Name	Group	Type
Precipitation	Climate	Driver
Evaporation	Climate	Driver
Groundwater	Hydrology	Driver
Feral species	Fauna	Ecology
Weed species	Vegetation	Ecology

3.2. Climate change and the hierarchy of objectives

Climate change adaptation requires complex decision-making processes for the near and more distant future taking into account environmental and climatic change. Structured decision-making can provide insightful ways to help address the complexities involved with identifying and prioritising key conservation values as well as choosing among alternative management strategies. Understanding these linkages through the formation of an objectives hierarchy is crucial for informed and transparent decision-making and integration, within an adaptive management framework.

When forming an objective hierarchy, objectives should be prioritised, with high-order objectives capturing the general intent and low-order objectives providing increasing detail (Kingsford and Biggs, 2012a). The ultimate vision for the desired state for the ecosystem should specify the fundamental long-term objective. Its wording should be a broad statement encompassing the multiple social, economic, and ecological goals. As such, it must be broken down into the relevant multiple objectives. These objectives provide a means of achieving the vision, and are derived from eliciting the key attributes, realising that some factors improve while others threaten each key attribute. Various factors are considered in the development of an objectives hierarchy: current condition, projections for future climate change, social, political, cultural objectives, and realistic expectations of what can be achieved over different periods.

3.2.1. Management of the Macquarie Marshes Nature Reserve

In January 1971 the Macquarie Marshes Nature Reserve was dedicated under the *National Parks and Wildlife Act 1967* (NSW) covering the area of Crown Land which was originally reserved in 1900 for the Preservation of Game. In 1919, the area was committed as a Bird and Animal Sanctuary; in 1943 a reserve for the Preservation of Native Fauna, and in 1955, a Fauna Protection District. In 2011 the Nature Reserve is managed by the New South Wales Office of Environment and Heritage under the *National Parks and Wildlife Act 1974* (NSW) (NPW Act).

The current management of the Nature Reserve is guided by the “Plan of Management” for the reserve, completed in 1993, and is intended for reviewed every 10 years. The reserve “Plan of Management” is a statutory document prepared under the NPW Act. Since this time, the reserve has experienced a decrease in the quality and quantity of its fundamental wetland values due to drought and the long-term impacts of water resource development, which has changed the hydrology of the system and caused a decrease in flood frequency, duration, and extent.

At present, significant work has been done in development of a hierarchy of objectives with Office of Environment and Heritage (NSW), detailing high-level objectives (OEH, 2012b). This project provides two key inputs:

- Strengthen the scientific basis for objectives based on collation of scientific data (3.1), form a process model of the ecosystem (3.3), and develop an information platform (3.5).
- Incorporate climate adaptation within the objective hierarchy based on a climate change synthesis identifying the likely risks, impacts of climate change, adaptation strategies and limits for the ecological and social communities of the Macquarie Marshes

3.2.2. Developing Strategic Adaptive Management Plan

The strategy draws upon a framework for adaptive management developed for managing conservation reserves with freshwater ecosystems [Figure 1,(Kingsford et al., 2011a)].

Following Nyberg (1998):

"Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form "active" adaptive management employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed."

The purpose of this adaptive management strategy is to provide a more flexible tool to complement the existing "Plan of Management" that can be reviewed and updated regularly to reflect changes in our understanding of the wetland system and changes in priorities. Adaptive management is designed to illustrate the linkages between key values, objectives, management actions, and monitoring.

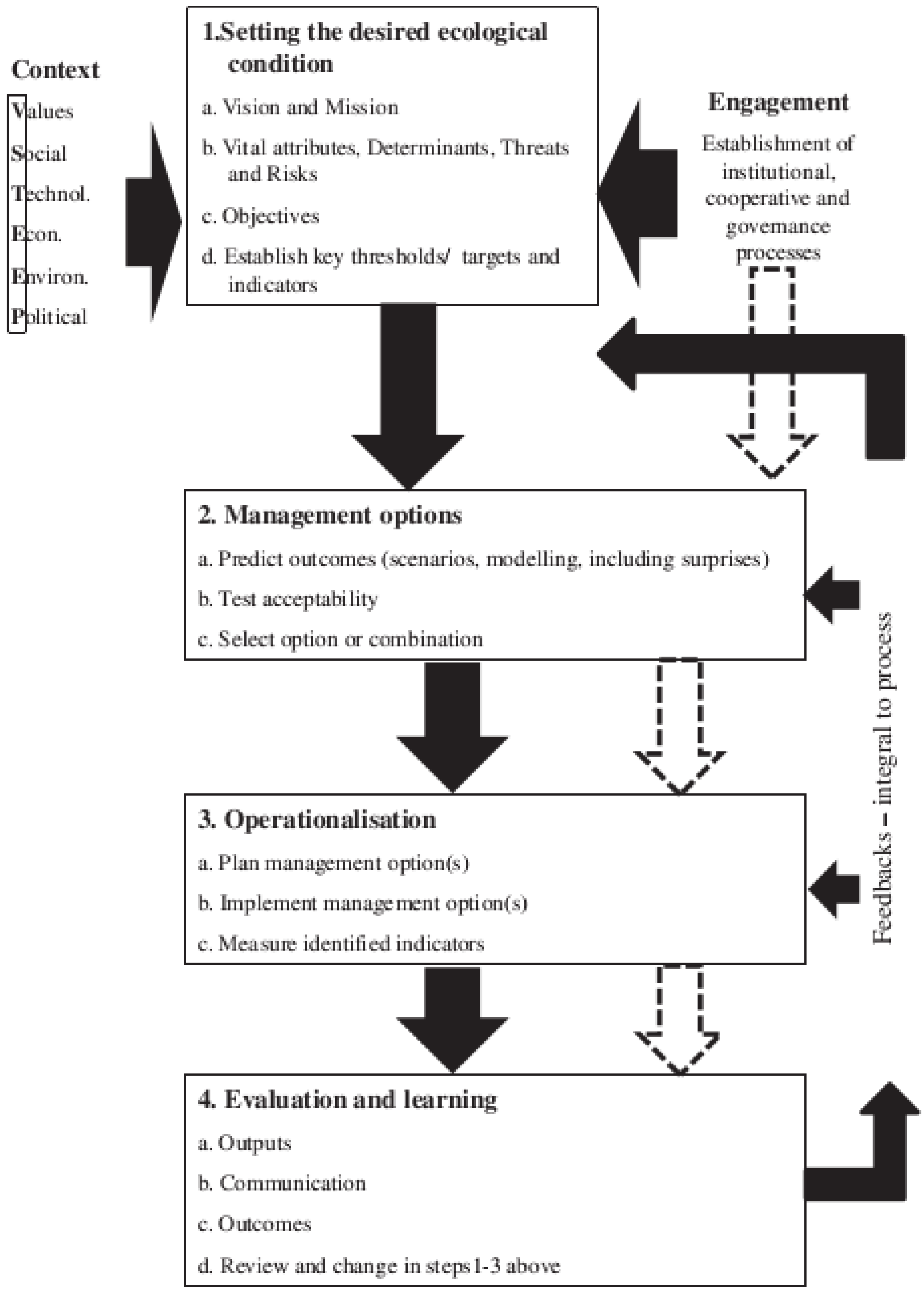
Vision and principles

The first step in the strategic adaptive management plan is to identify the desired future and ideal state of the Macquarie Marshes. Setting the vision and principles to inform adaptive management should be the first element, reflecting the context and values of the ecosystem (Table 4).

Table 4: The vision and the principles of the Macquarie Marshes (based on OEH's developing adaptive management framework)

Category	Descriptions
Vision	The Macquarie Marshes Nature Reserve is a place where frequent floods support abundant and diverse wildlife and communities
Principles	Conserve biological diversity, natural landscapes and processes to improve the health, resilience and ecological function of the Nature Reserve's vegetation and associated fauna
	Protect and enhance resources/features/customs that are valued by Aboriginal and other cultures and communities (subject to further determination involving cultural heritage stakeholders)
	Apply collaborative adaptive management approaches to manage and improve knowledge about the Nature Reserve's ecosystem
	Manage the Nature Reserve with optimism and transparency, acknowledging risk and uncertainty, applying rigour and expertise
	Collaborate with Aboriginal people, other landholders in the Marshes, stakeholders and communities in adaptive management activities
	Develop methods to manage the Nature Reserve to meet environmental responsibilities and legislative requirements.

Figure 1: Steps in a generic Strategic Adaptive Management framework [from (Kingsford and Biggs, 2012)].



Vital attributes, determinants, threats and risks

The second element sets out to list the key ecological components of the ecosystem (i.e., vital attributes), their drivers (i.e., determinants), and stressors [

Table 5; (Ogden et al., 2005)]. Drivers are the natural forces (e.g., sea level rise) or anthropogenic (e.g., water management) that occur outside the natural system, which have large-scale influences on natural systems. Stressors are physical or chemical changes that occur within natural systems affected by drivers, causing significant changes in biological components, patterns, and relationships in natural systems. Identified key ecological components should then form the basis for planning and objective setting. For each, the main processes ensuring resilience are then listed and the likely threats to desired state are identified and amenable to management. Together, these should provide a compressive framework for management.

Table 5: Key biophysical values, drivers, and stressors of the Macquarie Marshes Nature Reserve

Key values	Drivers	Stressors
Fauna Waterbirds breeding Invertebrate abundances Frog diversity Semi-permanent wetland vegetation River Red Gum community Common reed beds Floodplain vegetation Coolibah and Black box Woodlands Water Couch Open lagoons	Appropriate water flow and inundation regime – frequency, quantity, duration, extent, timing Diversity of healthy ecological communities Appropriate geomorphic characteristics Appropriate fire regimes Adaptive and responsive conservation management Adequate knowledge of the system and changes	Changed water regimes Invasive species plants, animals Changed geomorphic characteristics Inappropriate fire regime Climate change Pollution events

Objectives

A key element is the formation of an explicit hierarchy of objectives, starting at high order objectives, capturing the management intent or vision down to lower order and detailed objectives of desired condition. Objectives must be clearly defined with concise and explicit links. As an adaptive management strategy, the broad objectives may be stable over time but can also change. However, the prioritisation of objectives, lower level objectives and management options, will be revised according to changes in the conditions of the ecosystems and changes in management approaches. High-level objectives capture intent while low order detailed objectives link to ‘‘on-the-ground” interpretation of desired condition. Objectives should be cross-linked for integration.

For the Macquarie Marshes Nature Reserve, four high-level objectives have been established by OEH (2012b):

- Ecosystem Objectives
- People Objectives
- Balancing Objectives
- Enabling Objectives

Below we exemplify the hierarchy structure of objectives for Ecosystem Objectives (Figures 2-8).

Figure 2: High-level objectives established for the Macquarie Marshes Nature Reserve with detailed lower level Ecosystem Objectives [from (OEH, 2012b)]

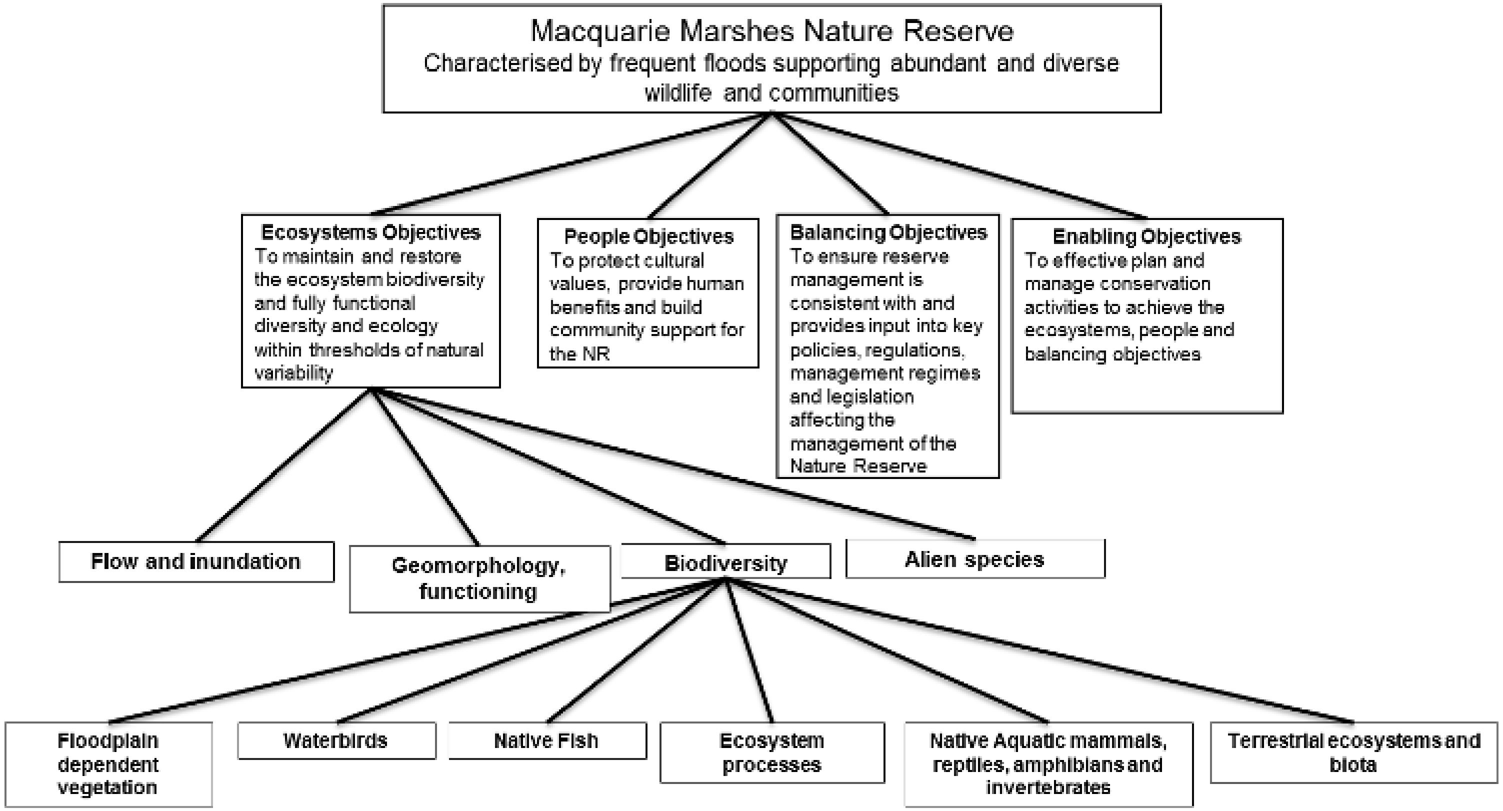


Figure 3: Floodplain dependent vegetation [from (OEH, 2012b)].

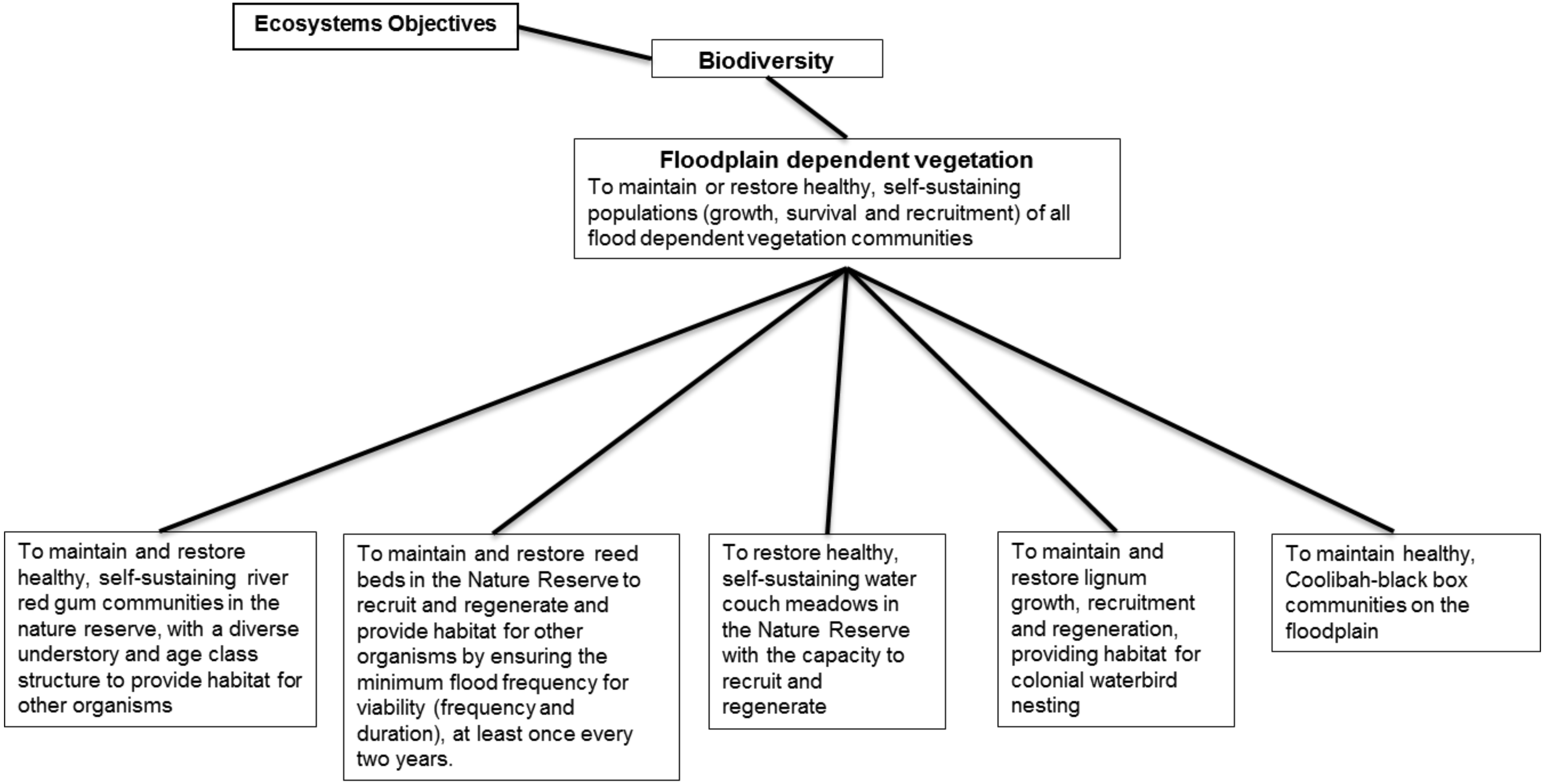


Figure 4: Waterbird [from (OEH, 2012b)].

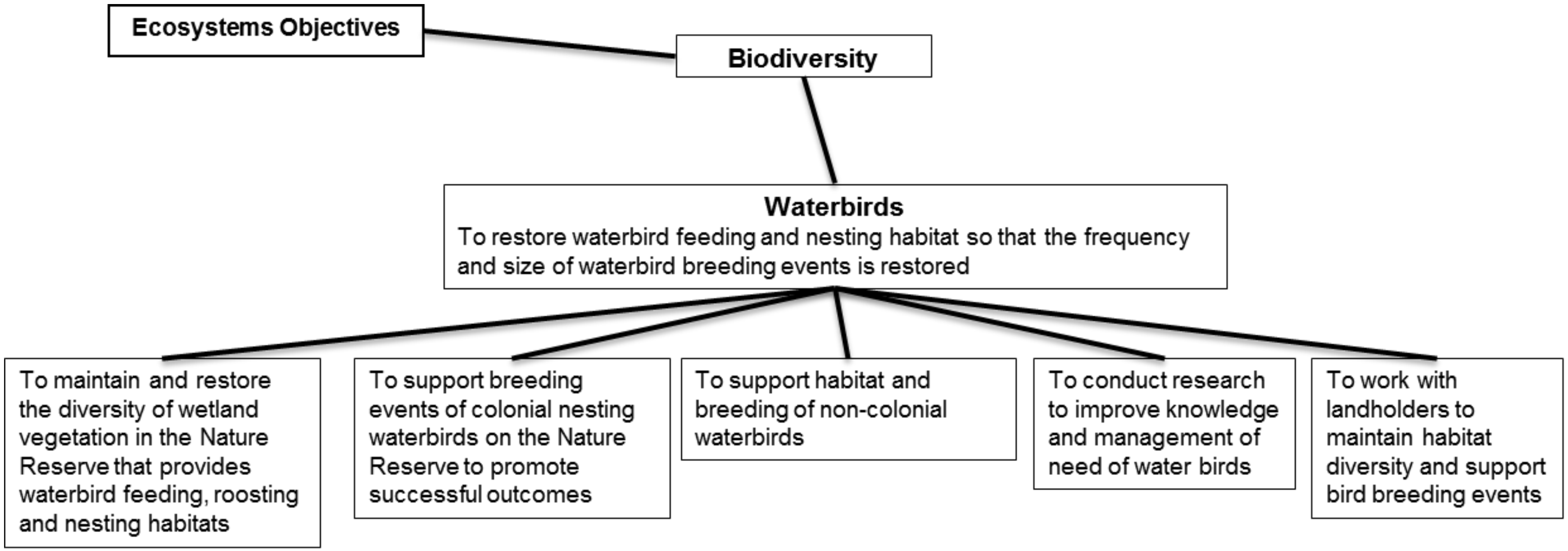


Figure 5: Native fish [from (OEH, 2012b)].

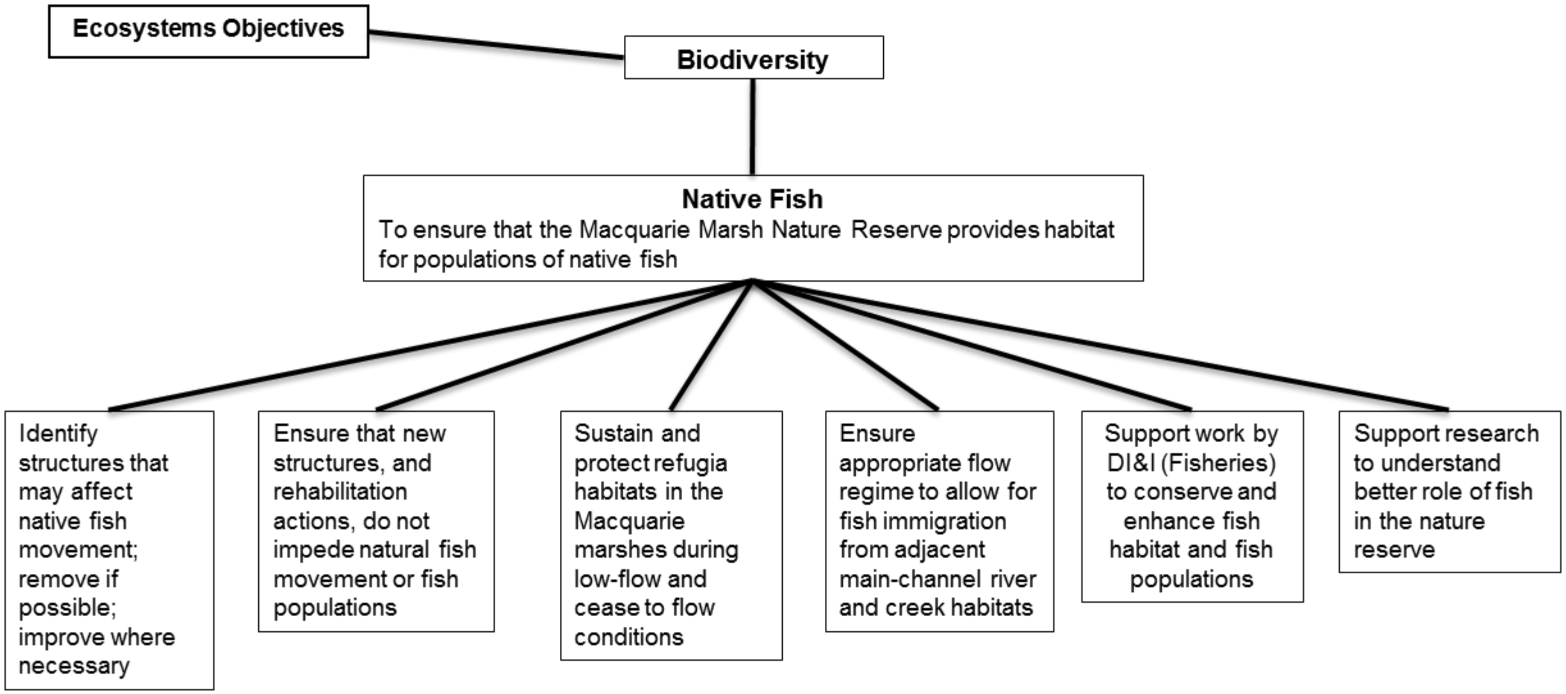


Figure 6: Ecosystem processes and food webs [from (OEH, 2012b)].

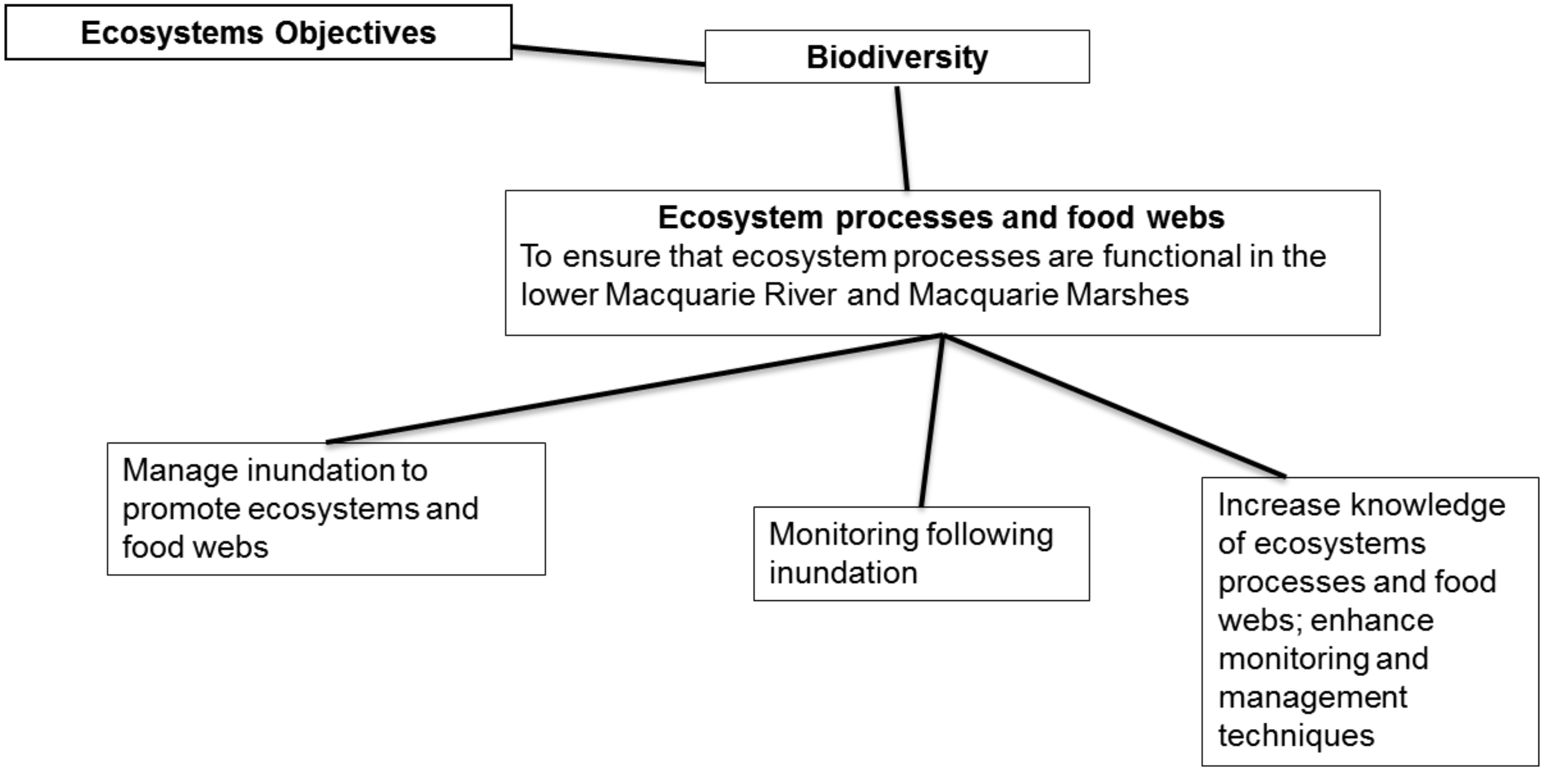


Figure 7: Native aquatic fauna [from (OEH, 2012b)].

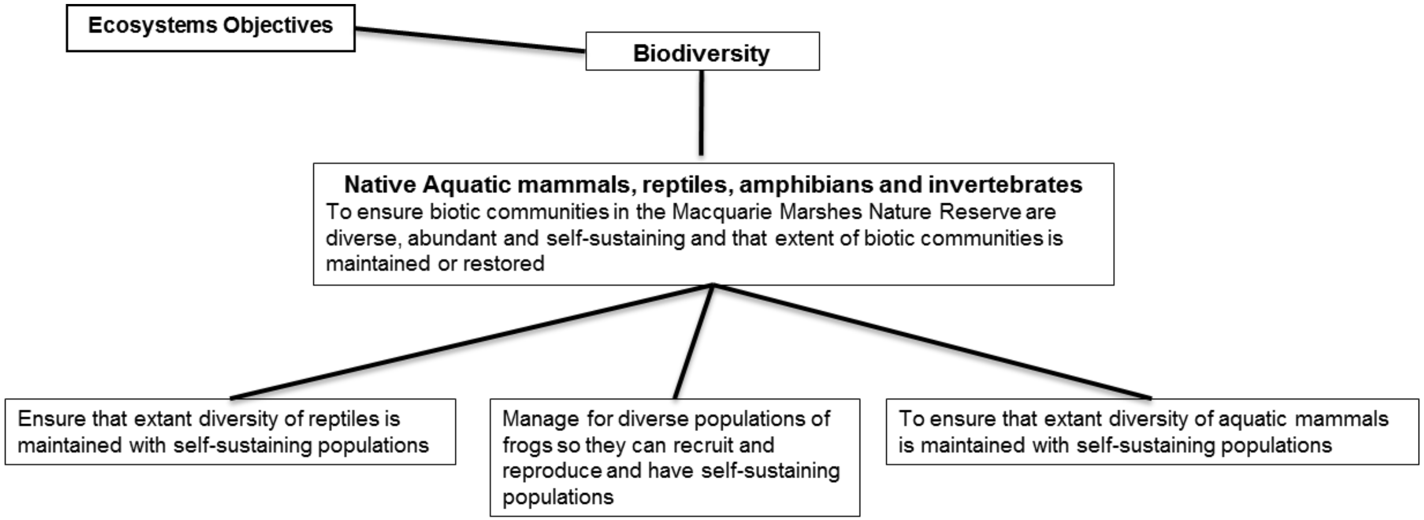


Figure 8: Native terrestrial fauna [from (OEH, 2012b)]

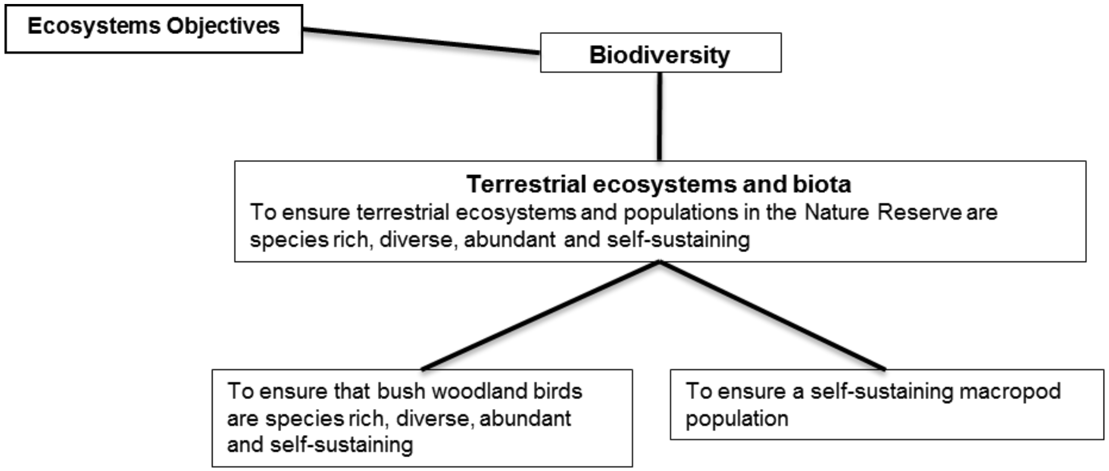


Table 6: Further objectives presently under development by New South Wales Office of Environment and Heritage (2012)

High-level objective	Mid-level objectives	Low-level objective
Ecosystem Objectives	Flow and inundation	Surface water
		Ground water
		Surface water / ground water interaction
	Geomorphology	Erosion
		Sedimentation
	Biodiversity	
	Flood dependent vegetation communities	River red gums
		Common reed beds
		Water couch community
		Coolibah-black box community
	Native fish	
	Waterbirds	
	Ecosystem processes	
	Native aquatic Fauna	Reptiles
		Frogs
		Aquatic mammals
	Terrestrial ecosystems and biota	Woodland birds
		Macropods
	Alien species	
People Objectives	Aboriginal cultural heritage	
	Partnerships with land managers	
	Tourism, visitation and education	
Balancing Objectives	Ramsar	
	Development and rehabilitation	
	Threatened species and protected species	
Enabling Objectives	Reserve planning	
	Management and development	
	Knowledge needs and science	Monitoring
		Science
	Water management	

Figure 9 High-level People Objectives [from (OEH, 2012b)].

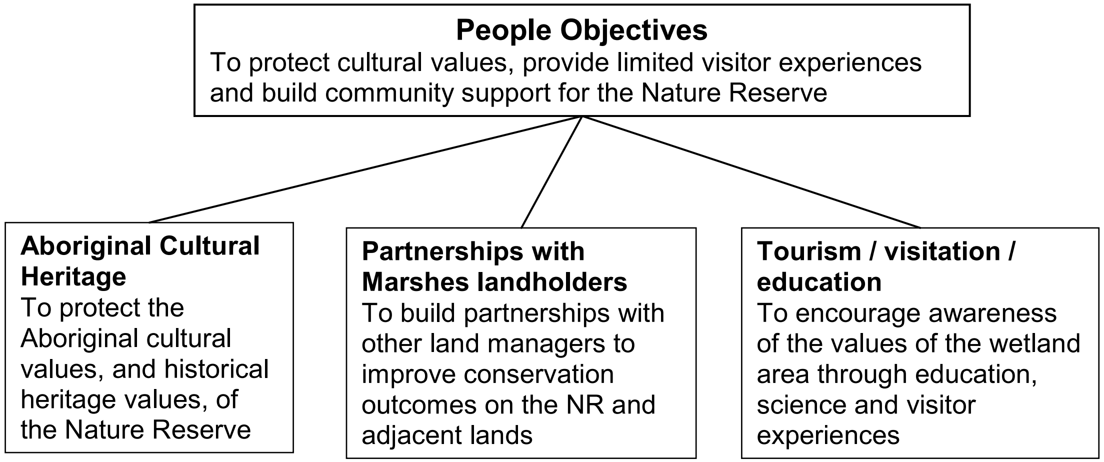


Figure 10 Lower-level People Objectives [from (OEH, 2012b)].

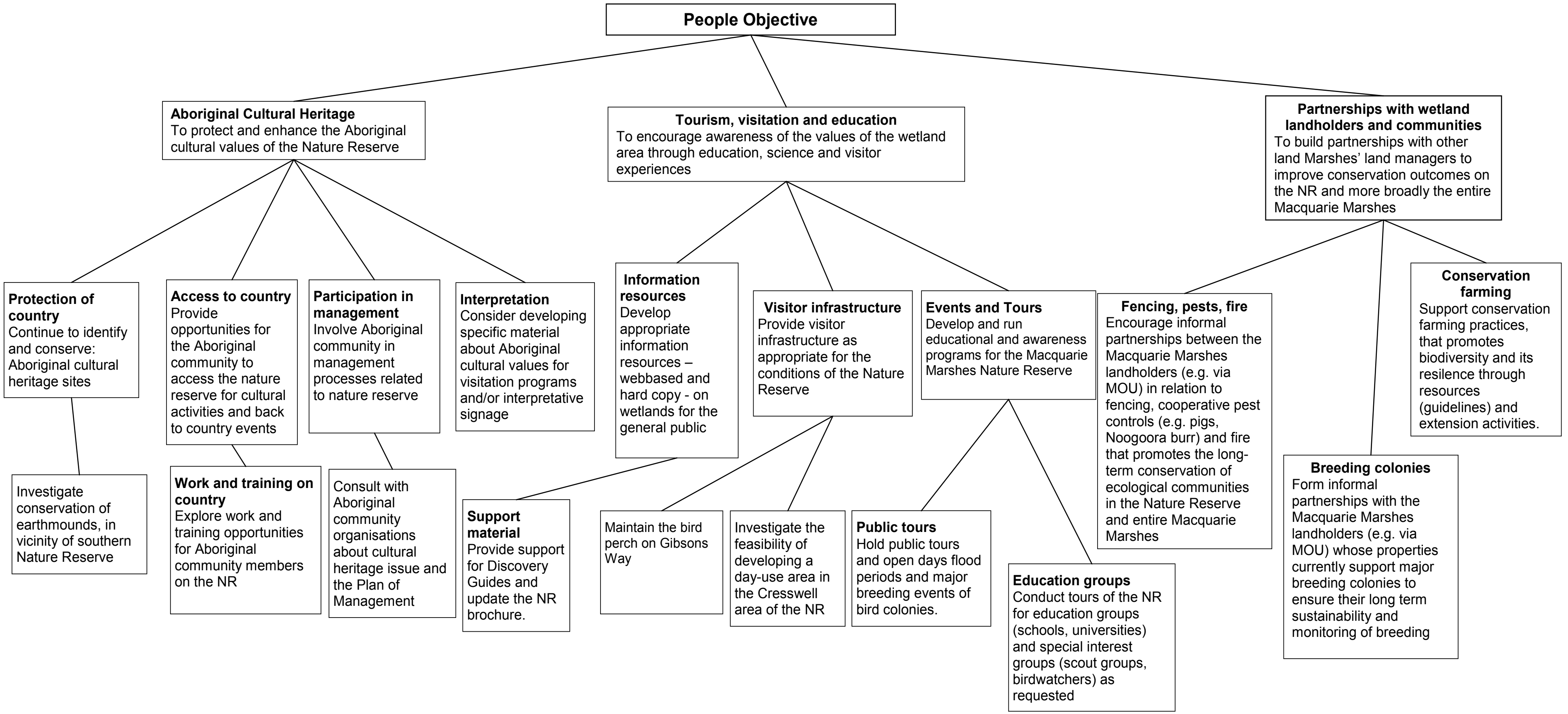


Figure 11 High-level Balancing Objectives [from (OEH, 2012b)].

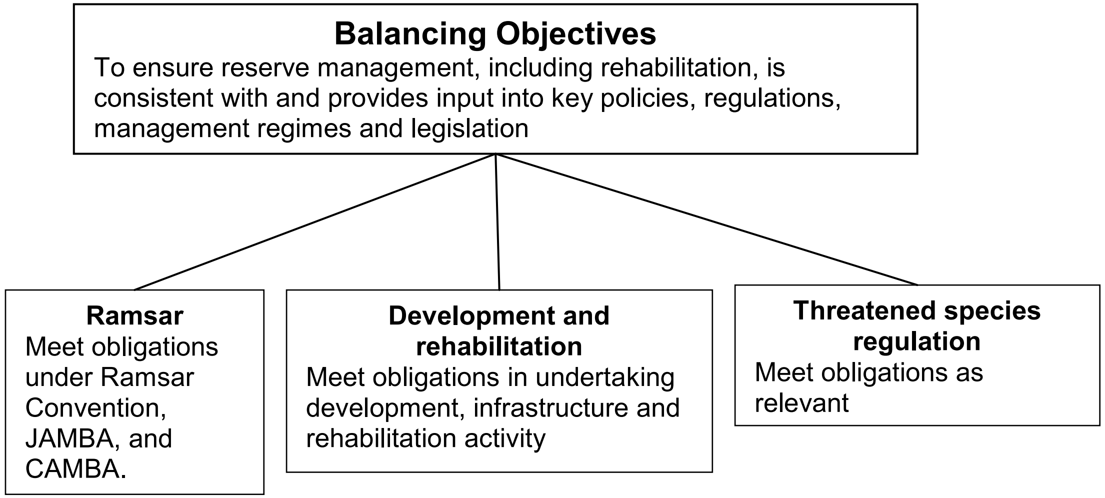


Figure 12 Lower-level Balancing Objectives [from (OEH, 2012b)].

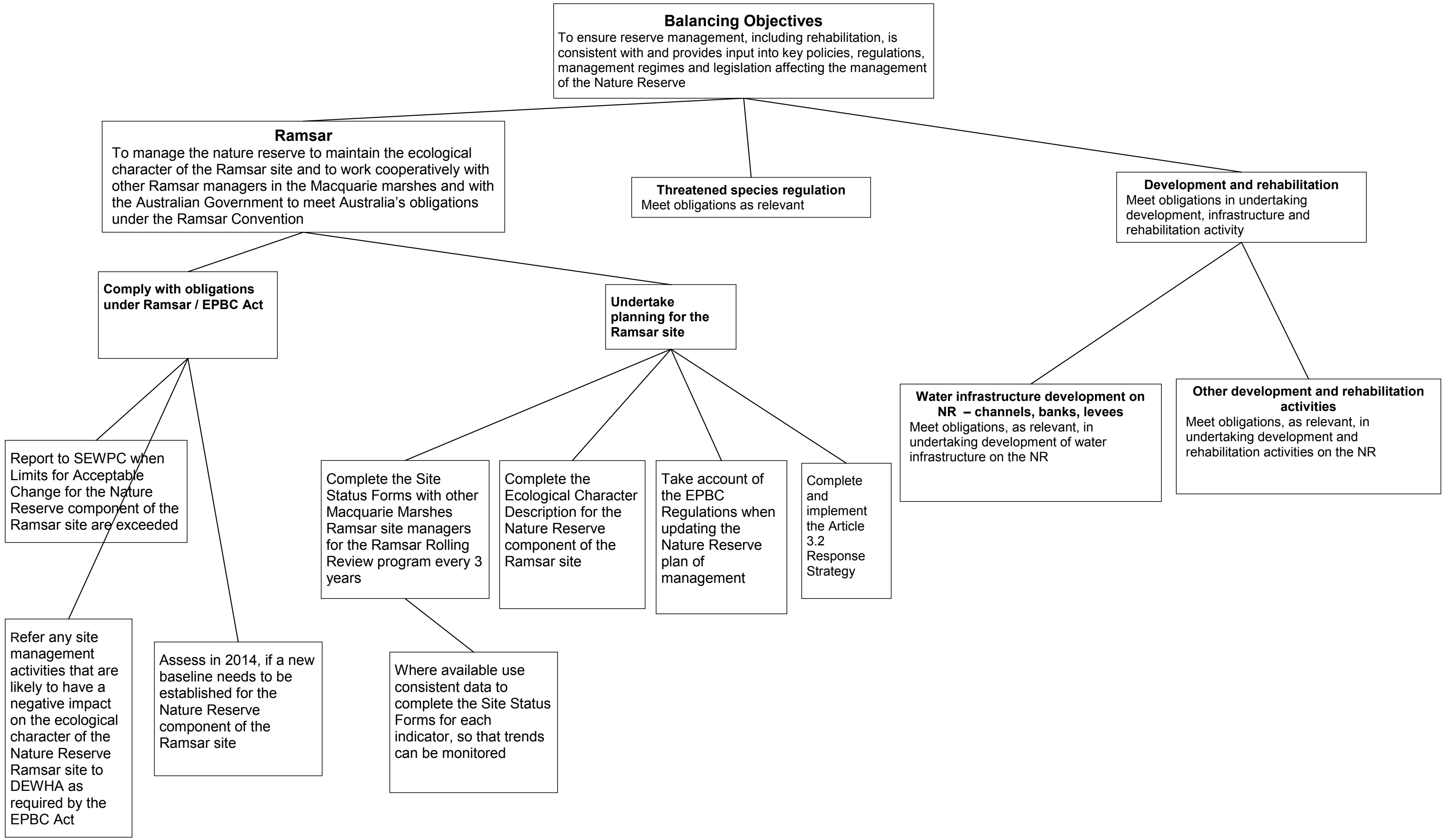


Figure 13 High-level Enabling Objectives [from (OEH, 2012b)].

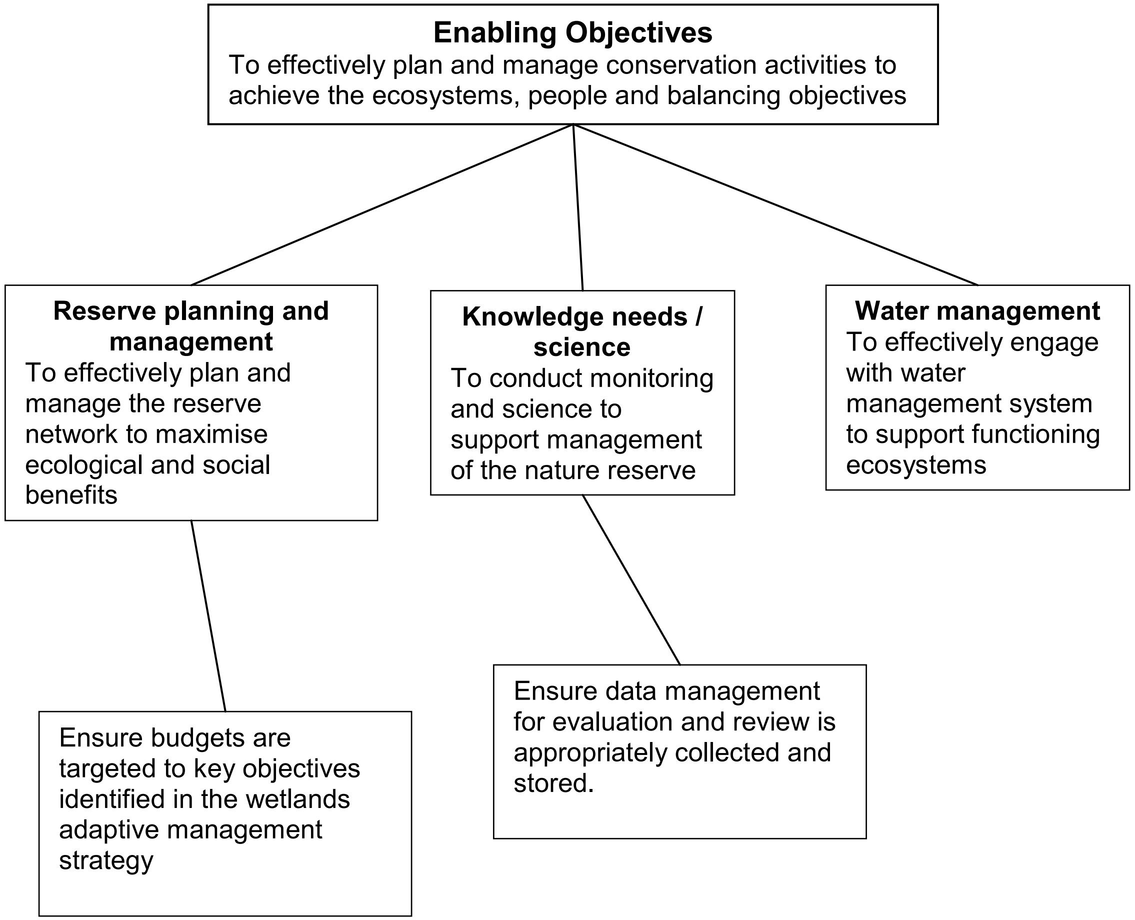


Figure 14 Lower-level Enabling Objectives [from (OEH, 2012b)].

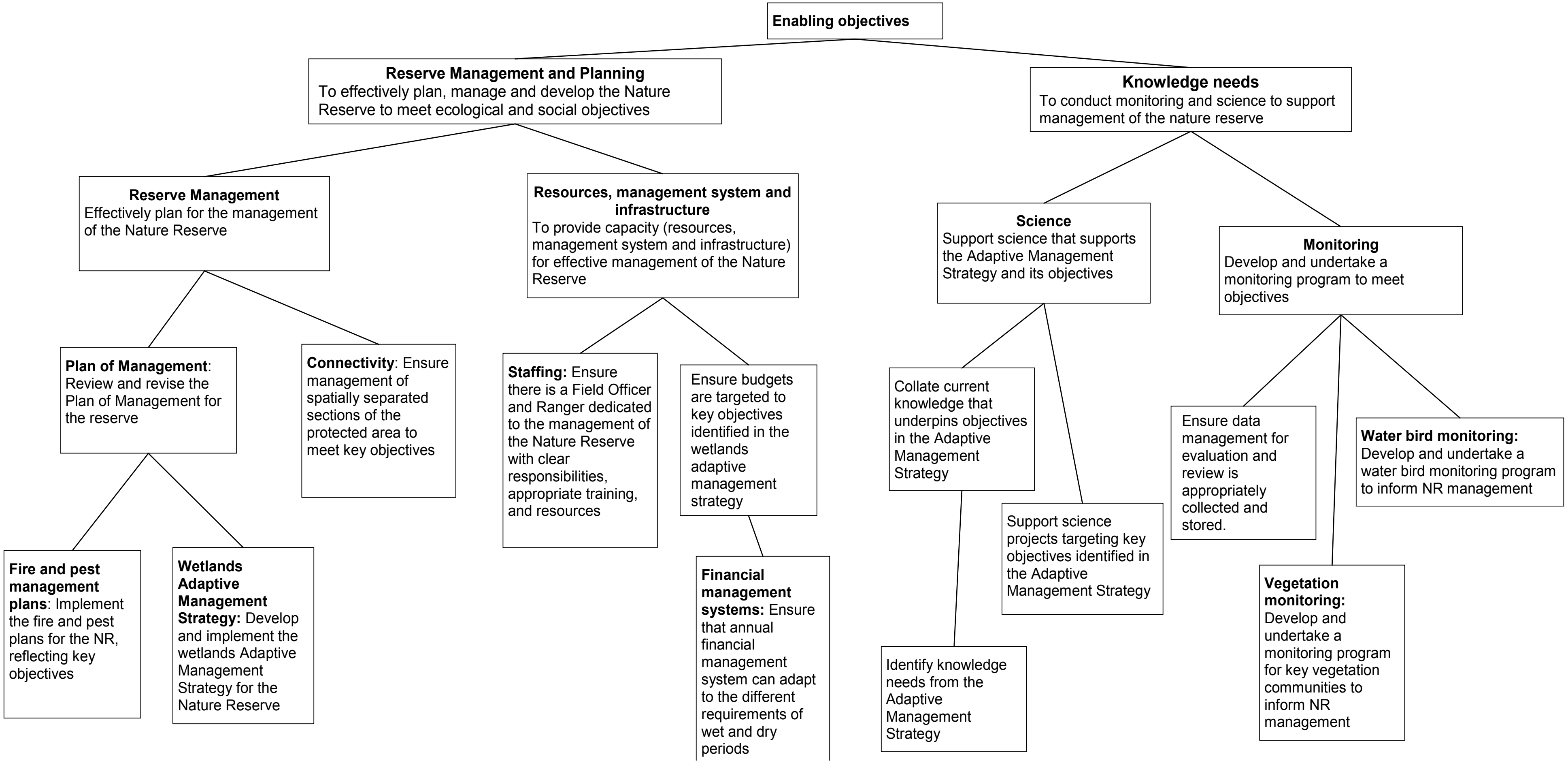
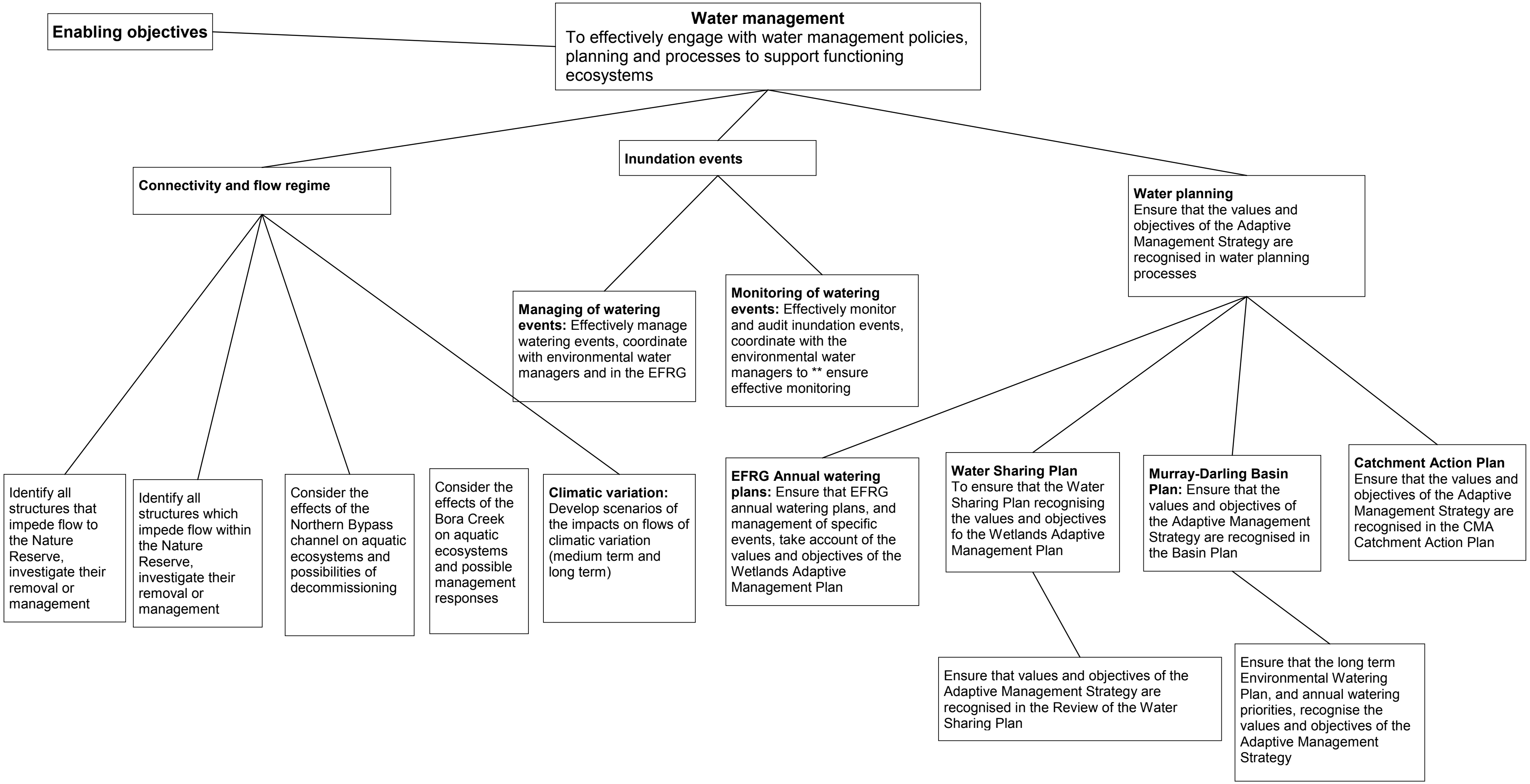


Figure 15 Lower-level Enabling Objectives [from (OEH, 2012b)].



Thresholds, restoration targets, and indicators

For each of the key values, appropriate indicator/s should be identified. These should reflect the vital attributes required for long-term viability (Table 7). Indicators should be sensitive to change and could be measured using a range of methods, forming operational goals that articulate the natural spatial and temporal variability. Developing thresholds of potential concern (TPCs) provides a measurable end-point within the strategic adaptive management framework (Kingsford and Biggs, 2012a). TPCs enable setting desirable ecosystems states or conditions against which the success of management actions can be evaluated. As defined by Biggs and Rogers (2003), TPCs are '*those upper and lower levels, along a continuum of change in selected environmental indicators that provide the basis for decisions on the acceptability of that change'*. Importantly, TPC's should represent points that once crossed, would change management decisions. Thresholds and indicators may involve sophisticated modelling (see sections 3.3.2-4) and/or sensible heuristics ('rules of thumb'), based on experience or even educated guesses (see section 3.3.1). Uncertainty in thresholds may also be resolved over time. Thresholds are operational goals that define natural spatial and temporal variability, within certain confidence intervals, relative to a potentially natural level.

For some systems, degrading conditions have meant that the thresholds of potential concern have already been crossed. In such cases, TPC's can be best described as the inverse, namely targets for rehabilitation, and act to inform the objectives by establishing targets for rehabilitation. They then become targets to work 'back towards' the desirable condition, as often thresholds may have already been exceeded. In a highly compromised system such as the Macquarie Marshes, TPCs can be usefully restated as targets for rehabilitation within the context of increased flows to the system. This captures the notion of resilience of ecosystems where indicators and their thresholds identify when a particular ecosystem moves to an undesirable condition (Table 7). For example, restoration of 1756ha of river red gum crown to good condition would immediately return to being a lower bound for a threshold of potential concern.

Each threshold should represent an achievable environmental goal and not designed to be overwhelming or too rigid. They also need to be firm enough to meet essential criteria of transparency should they be exceeded. The threshold themselves are open to ongoing scrutiny, but not when exceedence is reported, given likely contentiousness. At this time, it is far better to act and learn. Further, allowing sudden recalibration undermines the whole adaptive management system and means the status quo will likely never be found wanting. This underscores the importance of buy-in, or co-creation by researchers, managers, and key stakeholders of the rationale for thresholds and their levels. Identification of indicators and thresholds is an iterative process, it may be necessary to alter or add to the list of indicators, and thresholds after testing the suitability of different management options (see section 3.3).

Table 7: Examples of key values, their selected indicators and the thresholds of potential concern (TPC) and restoration targets as identified by OEH for the Macquarie Marshes (OEH, 2012b)

Key values	Indicator	TPC
Inundation patterns	Inundation frequency and extent	16 events > 350GL, over 20 year cycle
Waterbird breeding and habitat	Habitat and breeding events	Adequate habitat for breeding every 2-3 years
		Large breeding event every 10 years
	Extent of habitat	Extent of breeding habitat maintained or restored
	Diversity of habitat	Range of wetlands communities to support breeding maintained or restored
River Red Gum	Extent and condition	To maintain 100% 1427ha of river red gum communities, which is currently in good health, with a healthy understorey in good condition at all times
		To restore approx. 3570ha of river red gum community, current in poor condition, to intermediate, or better
		To restore approx. 1756 ha of river red gum communities, which is in intermediate condition, so that the crown condition is good and there is a diverse understorey of aquatic plants, grasses and forbs that respond to changes in wetness
Common reeds	Extent and condition	Maintain 1800 ha of reed bed in the northern section of the Nature Reserve restore a further 600 ha in the southern section of the Nature Reserve
Open water lagoons	Frequency of filling and area restored	Maintain and restore at least 70 ha of open water lagoons
Coolibah and black box community	Extent Coolibah black box	That current extent of black box and coolibah within the NR does not decrease
	Understorey Coolibah black box	That the understorey composition improves as indicated by including semi-permanent wetland communities, grassland and chenopods
Feral pigs	Effort per unit culled	That control efforts reduce feral pigs populations by >70% per year.

Thresholds of Potential Concern – derivation using data

It is possible, using long-term data, to provide a series of potential thresholds of concern or targets of rehabilitation, built around different confidence intervals for the data. We demonstrate this for colonial waterbirds breeding (see section 3.3.2 for more details) and river red gum health (see section 3.3.4 for more details). For example, the long-term (1986-2011) average abundance of colonial waterbirds across 16 colonies in the Macquarie Marshes is 17,087 with upper 75% confidence intervals of about 15,230 waterbirds (Table 8). A higher bound could be the 90% confidence interval of about 75,230 waterbirds (Table 8). These values can be established as targets of rehabilitation achieved through strategic management of environmental water allocations (see section 3.3.4 for discussion). Clearly, in such a system total abundance is highly variable and can represent species of less concern and so unique species may be more a useful variable (Table 8). This may be further developed by specifying the period between breeding events of certain magnitude. Further, such a threshold may be examined within the context of the likely natural thresholds and frequencies of colonial breeding (Kingsford and Johnson, 1998), tested through assessment of environmental flow scenarios (Kingsford and Auld, 2005a).

Table 8: Potential targets of rehabilitation set by upper (75% and 95%) Confidence Intervals (CI) of mean for colonial waterbird abundances (1986-2011). Frequencies in parentheses refer to the one in ten year frequencies when these levels were exceeded.

Colonial waterbirds	Average	0.75% CI	0.90% CI
Total Abundance	17,087	15,230(2.3)	75,230(0.08)
SNI	10,560	9,850(2.3)	53,083.9(0.8)
WHI	926	775(2.3)	3,167.7(0.8)
GLI	381	500(2.7)	1,360(0.8)
IE	3,783	4137(2.3)	197,90(0.8)
GE	99	105(2.3)	230(0.8)
CE	24	14(2.3)	115(0.8)
LE	333	231(2.3)	1,670(0.8)
LBC	97	112(2.3)	417(0.8)
LPC	106	157.5(2.3)	460(0.8)
NH	779	350(2.7)	1278(0.8)

[1] Species abbreviations: IE – Intermediate egret, LE – Lesser egret, CE – Cattle egret, GE - Great egret, LBC – Little black cormorant, LPC – Little pied cormorant, NH – Night Heron, SNI – Straw neck ibis, GLI – Glossy ibis, WHI – Australian white ibis. 2 RRG - River red gum woodland.

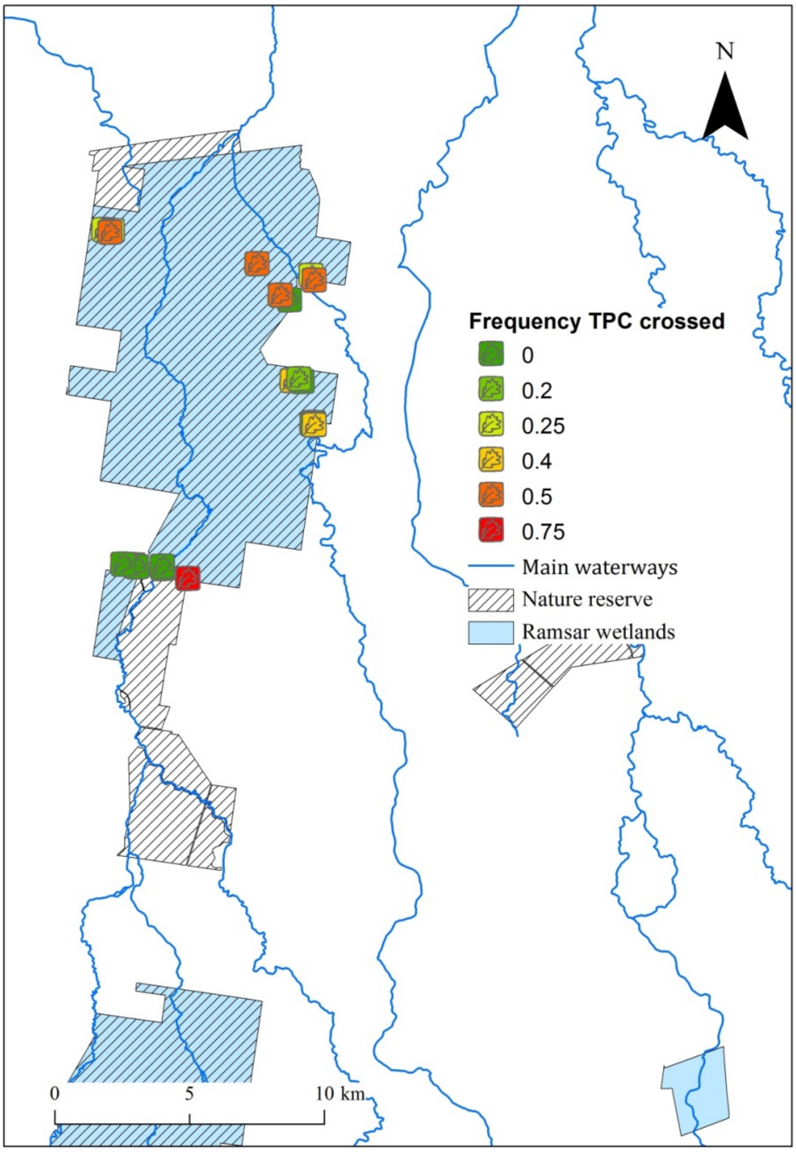
As well, river red gum health metrics can be used to identify threshold of potential concern relevant to this species, which once crossed would require either alteration of existing management practices or launching new ones (Table 9). The strong spatial component of vegetation to localised conditions means that we can establish more spatially explicit thresholds of potential concern for different locations within the Macquarie Marshes (Figure 16). Using river red gum data (Bacon, 2004, Catelotti, 2012), we estimated confidence intervals both across years (2004-2005, 2011) as well as across individual trees sampled at various locations around the Macquarie Marshes.

Similar thresholds may be easily derived for other response variables providing some quantitative basis for assessment. Actual choice of the threshold of potential concern needs to be a process involving other stakeholders and managers in determining thresholds that relate to values.

Table 9. Potential thresholds of concern provided by lower (19% and 25%) Confidence Intervals (CI) of mean for river red gum health (2003-2005, 2012). Frequencies in parentheses refer to the frequencies individual trees exceeded these limits.

Health metric	Average	0.10% CI	0.25% CI
Crown position (0-5)	3.44	1.48(0.76)	2.22(0.63)
Crown size(0-5)	2.97	1.26(0.08)	2.04(0.22)
Crown density (0-9)	4.27	1.43(0.08)	2.35(0.21)
Epicormic growth (0-5)	1.89	0.72(0.08)	1.4(0.22)
Dead branches (0-3)	2.38	0.82(0.08)	1.6(0.21)

Figure 16: Average frequencies where individual river red gum trees have crossed thresholds of potential concern (25%CI) within the Macquarie Marshes Nature Reserve.



3.2.3. Climate change impacts in the Macquarie Marshes

Flooding

Global projections for climate change indicate reduction in wet basins with increased proportions of dry basins (Milly et al., 2005). Within the Murray-Darling Basin, reductions in total runoff has been experienced as a consequence of rising air temperatures, evapotranspiration, which have been compounded by in stream structures and land use (Timbal and Jones, 2008, MDBA, 2010). Presently experienced rise of 1°C in average temperature has translated to a 15% reduction of inflows and this is projected to further decrease by 55% assuming temperatures continue to rise to 2°C in average temperature by 2060 (Cai and Cowan, 2008). In the southern Murray-Darling Basin, water availability for environmental flows is estimated to decrease between 32% and 44% (depending on climate change scenarios) if drought conditions endure as in the previous decade (Aldous et al., 2011). Reduction in flows will likely limit the frequencies of natural overbank flows, further increasing the dependency of many wetlands on targeted environmental flow allocations (Aldous et al., 2011). Within the Murray-Darling Basin, annual streamflow may fall 10-25% by 2050 and 16-48% by 2100 (Hennessey et al., 2007).

Evaporation

Potential evaporation (or evaporative demand) is likely to increase, which when combined with reduced rainfall will lead to reduced soil moisture and runoff over most of Australia (Hennessey et al., 2007). Annual average potential evaporation increases by 0% to 8% per degree of global warming over most of Australia and up to 12% over the upper catchment areas of the Murray Darling Basin (CSIRO, 2008b). All models tested by CSIRO (2008) simulate an increase in potential evaporation over the Murray-Darling Basin, with the highest increase where rainfall decreases such as the Macquarie Marshes.

Water temperatures

Aquatic ecosystems are sensitive to climate change due to the strong positive correlation between surface air temperatures and water temperatures (Morrill et al., 2005). Over the past 13 years (1994-2007), average freshwater temperatures have been increasing at a rate of 0.12°C per annum (Chessman, 2009b). This was attributed to increased air temperature by 0.09°C per annum, greater radiant heat due to shallower water bodies, and reduced cool groundwater inputs (Chessman, 2009b). Based on these historical figures, water temperatures are set to increase 1°C by 2020 and almost 5°C by 2050. Rising water temperatures will exacerbate other stresses of freshwater ecosystems such as reduced flooding and declining water quality (Le Quesne et al., 2010, Viers and Rheinheimer). The direct relationship between water temperature and dissolved oxygen will mean reduction in the latter (Caissie, 2006).

Bushfires

Globally, area burned and fire occurrences are set to increase owing to climate change (Flannigan et al., 2009). Future climate scenarios predict shifts in timing, amplification, and length of fire seasons in temperate areas (Flannigan et al., 2009, Rogers et al., 2011). The culmination of rainfall deficiencies, low atmospheric humidity and high daytime temperatures has historically resulted in early curing of fuels throughout southeast Australia (Taylor and Webb, 2005) and predictive studies indicate that a decrease in humidity and increase in temperature will be driving forces behind changes in fire danger for Australia into the future (Flannigan et al., 2009). Under doubled CO_2 conditions it is predicted that most of Australia will see an increase in fire danger of 10-

30% (Beer and Williams, 1995, Williams et al., 2001), with an estimate for a maximum 200% increase in fire danger during peak fire season in some areas of the country (Pitman et al., 2007). There is likely to be a reduced interval between fires, increased fire intensity, a decrease in fire extinguishments and faster fire spread. In southeast Australia, the frequency of very high and extreme fire danger days is likely to rise by 4-25% by 2020 and 15-70% by 2050 and across Australia the fire season length is likely to extend (Hennessey et al., 2007). The forest Fire Danger Index (FFDI) is a function of dryness, temp, wind speed and humidity (Clarke et al., 2011). The number of extreme fire danger days is projected to increase by at least 5-25% by 2020 (under low global warming scenarios i.e.+0.4°C (Lucas, 2007). More recent research, building on Hennessey et al. (2007), using A2 emission scenarios from the Special Report on Emissions Scenarios (SRES), (Nakicenovic et al., 2000, Clarke et al., 2011), project a small decrease in FFDI by 2050 but an earlier fire season, and earlier and more intense fire season by 2100 (Clarke et al., 2011). The Macquarie Marshes experienced a series of damaging fires during the Millennium Drought. During similar periods, it is likely that such fires would occur again.

Water quality

Air temperature and precipitation changes, causing changes in water temperature and streamflows, are predicted to be key drivers in the decline of surface water quality(Beare and Heaney, 2002, Whitehead et al., 2009, Rehana and Mujumdar, 2011). By 2050, annual stream flows are projected (A1 climate change scenario) to drop by by 14-25% and salinity to change by -8 to +19% (Beare and Heaney, 2002). There is a probable chance (50%) that by 2020 the average salinity of the lower Murray River will exceed the 800 EC threshold set for desirable drinking and irrigation water (Mdbmc, 1999). Toxic algal blooms are likely to be more frequent and to last longer (Hennessey et al., 2007). By 2050, salinity caused by low flow is projected to increase by 19% (Beare and Heaney, 2002). Other estimates predict end-of-river salinity to increase by 20% by 2070 in the Macquarie-Bogan Rivers (Austin et al., 2010). Additionally, prolonged drought and extreme rain events have the potential to increase rapid nutrient inputs in surface run-off (Whitehead et al., 2009, Quevauviller, 2011) resulting in algal blooms (Vilhena et al., 2010). While not fully investigated in south east Australia, total suspended solids and phosphorus concentrations are predicted to increase under IPCC SRESs in North American waterways (Wilson and Weng, 2011). Warmer water may cause prolonged stratification in standing waters, shifting the timing of nutrient cycles (Taner et al., 2011) and may also affect chemical reaction kinetics, altering contamination mobility and dilution (Whitehead et al., 2009, Carere et al., 2011).

Erosion

Evidence suggests that climatic shifts towards arid conditions, where the severity of flooding events magnify, have increased fluvial erosion rates (Molnar, 2001). Increased runoff intensity coupled with decreases in vegetation during shifts in climatic cycles has historically contributed towards the rapid expansion of river channels (Tucker and Slingerland, 1997). In the Murray-Darling Basin sediment production and accumulation has been linked with increased water temperatures through the Lower to Middle Miocene (Lukasik and James, 2006) suggesting a correlation of climate change and erosion. For climate change, many of the drivers and stressors remain the same as currently affected by river regulation (Jenkins et al., 2011).

Groundwater

Knowledge gaps remain regarding the impacts of climate change on groundwater (Barron et al., 2010). However, climate change will likely affect groundwater recharge (Austin et al., 2010, Ng et al., 2010, Auterives et al., 2011), which may be compounded as a result of doubling of atmospheric CO_2 leading to increased vegetation and increased water use (Austin et al., 2010). Under a dry future scenario, groundwater recharge is predicted to decrease by 12% on average across the M-D Basin (Crosbie et al., 2010). Areas projected to receive lower rainfall such as southern Australian water tables are expected to experience decreased groundwater recharge (Barron et al., 2010). The impacts of climate change on groundwater tables have already been recorded across many parts of the Murray-Darling Basin. The recent drought period (2001-2008) has caused an average groundwater table fall of 1m across the Murray-Darling Basin (Leblanc et al., 2009). Between 1990 and 2006 river modification stressors compounded by climate change impacts saw an average drop of 1.4m in groundwater under many Murray River Floodplains (Mac Nally et al., 2011). Groundwater models (CSIRO, 2008c) indicate that for the Lower Macquarie Alluvium groundwater management unit, the change in net river loss would be zero under the best estimate for 2030 climate. The range of possibilities for net river loss is from a 0.3 GL/year greater loss under the dry extreme 2030 climate to a 0.4 GL/year less loss under the wet extreme 2030 climate. Water balance analyses of other groundwater management units in the region indicate that under the best estimate 2030 climate, recharge would not change significantly. In summary, the impact of climate change is minimal compared to the effect of increased groundwater extraction.

Uncertainty of regional climate models

Presently, the largest sources of uncertainty are due to the climate change projections and the modelled implications of climate change on regional rainfall. This is because most modelling approaches use downscaled Global Circulation Models (GCM) to derive regional climate models. Projections of temperature rise over the next 50 years have a high level of certainty (Bates et al., 2008), and have been successfully estimated by most regional models, including the CSIRO sustainable yields model (Perkins et al., 2007). However, projected changes in precipitation incur high levels of uncertainty both within and across models (Perkins et al., 2007, Bates et al., 2008). Changes in evapotranspiration rates carry great uncertainty, as they depend on a variety of factors, including air temperatures, water availability, and the response of vegetation (Aldous et al., 2011).

Table 10: Summary of projected change under climate change of drivers and stressors of relevance to the Macquarie Marshes ecosystem (Summarised from Jenkins et al. (2011)).

Category	Variable	Projected change
Driver	Temperature	increased
Driver	Rainfall	Highly variable estimates from -13% to +11%
Driver	Runoff	Highly variable estimates from -25% to +30%
Driver	Evapotranspiration	Highly variable estimates from -12% to +10%
Driver	Climatic variability	increase of extreme weather events, increased frequency of droughts
Stressor	Flooding	Reduced frequency and volume, increased frequency and magnitude of drought, reduced connectivity
Stressor	Evaporation	Increased
Stressor	Water temperatures	Increased
Stressor	Bushfires	Increased
Stressor	Water quality	Declined – increased salinity and algal blooms
Stressor	Erosion	Increased fluvial erosion rates, increased sedimentation in dams leading to reduction in storage capacity and subsequent amplification of flood risk
Stressor	Groundwater	Falling groundwater tables

Ecosystem

The Macquarie Marshes, similar to a number of low-lying wetlands across inland Australia, are subjected to extensive flooding by freshwater rivers and creeks. Floodplain wetlands provide critical aquatic and riparian habitat for many flood-reliant and flood-tolerant flora and fauna (Ralph and Rogers, 2009, Rogers and Ralph, 2010). They rely primarily on upstream flows (Kingsford and Thomas, 1995, Ren et al., 2010, Thomas et al., 2011a) but are also supported by local rainfall (Wen et al., 2011). Driven by climate variability, these wetlands experience changes in the frequency, magnitude, and duration of flooding as part of the natural cycles of rainfall and runoff. Over the course of the 20th century, floodplain wetlands have been particularly exposed to water resource management and development, significantly affecting their natural flood regime. Development and extraction of water is expected to continue in the 21st century, undoubtedly exacerbating their already declining ecosystem conditions (Kingsford, 2011, Finlayson et al., 2013). Under climate change, unfavourable conditions will likely exacerbate the changes to the natural cycles and may contribute to alterations in biophysical and ecological processes. Wetlands within regulated river basins, such as the Macquarie Marshes, will likely be affected more than those in free-flowing river basins (Palmer et al., 2008).

Increased temperatures and changes to hydrologic regimes brought upon by climate change may exceed tolerances of some aquatic biota (Palmer et al., 2008, Turak et al., 2011, Viers and Rheinheimer, 2011). Response of wetland ecosystems to environmental stressors, such as reduction in flooding events, are often nonlinear (i.e., thresholds), leading to loss of resilience and quick regime shifts. For example, due to the thermal tolerances of freshwater organisms, the change in temperature regime is expected to shift the boundaries of species and communities (Carpenter et al., 1992, Viers and Rheinheimer, 2011). Recorded historical increases in water temperatures have caused a shift in favour of thermophilic species (Chessman, 2009a). Already major regime shifts are occurring in many aquatic ecosystems as a result of changes to flow produced by river regulation (Gordon et al., 2008).

Vegetation

The Macquarie Marshes encompass seven major vegetation communities (OEH, 2012c), having different flow requirements that control their distribution (Roberts and Marston, 2000). Recent land clearing and river regulation have severely impacted the extent and condition of vegetation communities in the Marshes (OEH, 2012c). River red gum forests dominate the more frequently flooded areas, with a wetland understorey including aquatic species, reed, rushes and sedges (Paijmans, 1981, Keith, 2004). The sparser canopies of river red gum woodlands occur throughout less frequently flooded areas (DECCW, 2010b) with a grass and forb species understorey (Paijmans, 1981). The ability of black box to store seeds within their canopy and release when prevailing conditions are suitable may provide greater resilience for the species but will undoubtedly have an effect on quantity and viability of seeds. Both river red gums and black box may prove resilient to decreasing flood frequencies however long term viability remains at stake. Drying conditions will likely prove favourable for more dryland species such as poplar box, belah, and wilga. Different to floodplain tree species, lignum can withstand longer dry periods. However, decreasing inter flood frequencies will limit seed dispersal, increasing the likelihood of stochastic local extinctions beyond the core wetland areas. Ecotone zones between frequently flooded and dry area are inhabited by species such as grasses and sedges. Under drying conditions, the size of the ecotone will likely decrease, increased competition between species. Species able to vegetatively regenerate, such as common reed, may maintain viable populations, given sufficient water. Also, seed bank dependant species are likely to persist under drying conditions while those dependant on dispersal will struggle to maintain viable populations. Macrophytes will also be impacted by loss of flooding (Sabella, 2009).

Waterbirds

Long-term data on waterbird species richness and abundance show a marked decline in waterbird community health over the past few decades, reflecting the effects of resource development and longer term drought (Kingsford and Thomas, 1995, Kingsford and Porter, 2009). Reduction in flooding has also affected the frequency and extent of breeding events in the Macquarie Marshes (Kingsford and Johnson, 1998). Climate change will likely exacerbate the effects of existing resource development by further diminishing flows and flood events in the Marshes and increasing the time between flood events. Reduced inundation frequencies will mean reduction in frequency and scale of breeding events. Reasons include minimum requirement for colonially nesting, exposure to predators, build-up of food reserves for breeding, and loss of organic matter and reduced microinvertebrate diversity and densities (Larson, 1994, Kingsford and Johnson, 1998, Kingsford and Norman, 2002, Kingsford and Auld, 2005a, Jenkins and Boulton, 2007). These changes will limit the extent of their foraging and breeding habitat (Larson, 1994, Kingsford and Norman, 2002). Climate change is also projected to change the timing of breeding of waterbird (Butler, 2003, Murphy-Klassen et al., 2005, Beaumont et al., 2006).

Fish

Fish assemblages in the Macquarie Marshes are comprised of 21 species, numerically dominated by invasive communities (Rayner et al., 2009). Historical records report a decline in the number of native species observed between 1975 and 2006 (Jenkins and Wolfenden, 2006). Long-term water extraction from rivers during flood events has impacted fish assemblages in arid zone floodplain rivers (e.g. Rayner et al.(2009)), specifically by impacting on the large-scale long-term flooding sequence that often occurs in large river floodplain ecosystems (Leigh et al., 2010). Any reduction in frequency, duration and extent of floodplain inundation, will alter abiotic and biotic conditions in aquatic habitats and increase reliance on refugia. These changes will have variable impacts on fish species depending on species-specific habitat and life-history requirements such as flooding to promote spawning and recruitment, tolerances to water quality and habitat in residual refugial waterholes, and the competition with alien species. Based on current understanding and projections of future patterns in flooding regimes, reduced floodplain inundation will likely lead to increasing dominance (but not necessarily increases in density) of species that either recruit during low flows, are long-lived and/ or omnivorous. Site-scale richness (alpha diversity) is predicted to decline with increasing drying (Rayner et al., 2009). Decline will be slow initially as small, shallow reaches become dry, and increase as taxa sensitive to poor water quality, lack of floodplain habitat for life cycle processes or those vulnerable to predation in confined habitats become regionally extinct (e.g. Magalhães et al. (2002)). By 2070, the combination of climate change and increased water demand is projected to result in a loss of ~20% of the freshwater fish fauna of the Murray-Darling Basin (Xenopoulos et al., 2005). The abundance and biomass of alien species that occur in the Macquarie Marshes (common carp, gambusia, goldfish) are likely to have variable responses associated with climate change.

Invertebrates

Studies of invertebrates in the Macquarie Marshes report an estimate of 160 aquatic invertebrate species (Bray, 1994, Jenkins et al., 2004, Macrae, 2004, Jenkins et al., 2008). Flow reductions have already reduced freshwater invertebrate biodiversity, where only the more tolerant species survive (James et al., 2003, Jenkins and Boulton, 2007, Lawrence et al., 2010). Climate change will likely compound these stresses (reviewed by Woodward et al. (Woodward et al., 2010)), through modification of multiple drivers that influence invertebrates including elevated temperatures (Hogg et al., 1995), reduced rainfall (Brendonck, 1996), habitat loss (Palmer et al., 2008, Chessman, 2009a, Nielsen and Brock, 2009), increased salinity (Nielsen and Brock, 2009) and reduced flow (Chessman, 2009a).

Woodland birds

Semi-arid wetlands maintain a mosaic of highly productive habitat that supports a great variety of woodland birds (McGinness et al., 2010). In the Macquarie Marshes, 87 woodland bird species have been recorded (Blackwood et al., 2010). The sensitivity of these wetlands to river regulation has a direct link to the condition of woodland bird communities (McGinness et al., 2010). Across South-eastern Australia, these species are already experiencing declines due to the degradation, fragmentation, and destruction of woodland habitat, mainly through agricultural development (Montague-Drake et al., 2009, McGinness et al., 2010, Bennett and Watson, 2011). In the Macquarie Marshes, these changes are implicated in declines in woodland birds, brought about by reduced frequency and duration of flood events needed to support wetland vegetation, particularly the extensive communities of river red gum (Blackwood et al., 2010). Climate change is expected to exacerbate the loss of habitat, leading to the continued decline of woodland birds (Mac Nally et al., 2009). Although, further loss of water from the Macquarie Marshes due to climate change is likely to impact on woodland bird habitat, these impacts are insubstantial compared to the increasing water demands (Vörösmarty et al., 2000).

Frogs

Little is known about frog communities of the Macquarie Marshes compared to other organisms ((DECCW, 2010b) 2010a, but see (Macrae, 2004, Harrison et al., 2010)). Recent work recorded as many as 15 species (Ocock, J. pers.comm.). Findings suggest frog species have been declining across the Macquarie Marshes (DECCW, 2010b). These trends are likely a result of significant decreases in the extent and frequency of flooding and fragmentation of vegetation communities (Harrison et al., 2010). The projected impacts of climate change on vegetation, soil, and aquatic communities as well as the frequency of flooding and physicochemical conditions in the Macquarie Marshes may exacerbate these existing impacts (Blaustein et al., 2010).

Carbon cycling

Floodplain soils from the Macquarie Marshes have high levels of total carbon and nutrients, contributing to heterotrophic wetland conditions after flooding (Jenkins et al., 2009). Past changes to the flood regime of the Marshes have reduced the accumulation of organic matter on the soil surface, shifting the ecosystem toward net primary production (autotrophic) as the interval between flood events increases. This will likely reduce overall biodiversity (i.e., fish, waterbirds and macroinvertebrates) as the dual food web pathway simplifies with fewer products available to consumers. Organic matter are extremely susceptible to increase in the inter flood interval (Valett et al., 2005, Shah and Dahm, 2008). One such pathway is linked to loss of river red gums and the replacement by terrestrial species, which contribute relatively little organic matter. Consequently, organic matter and dissolved organic carbon decline although levels of organic matter and total carbon remain tightly coupled.

Table 11: Summary of significance, condition, key risks, and thresholds (reproduced from Jenkins et al. (2011)).

Ecological component	Condition	Risk	Habitat	Threshold Flooding	Threshold Drying
Waterbirds	Declining	High	Mosaic-reeds, red gum woodland with river cooba, water couch, etc.	Inundation lasting 4-5 months between August and March	Cannot exceed bird lifecycle (i.e. drying long enough so birds too old to breed)
Vegetation	Declining	High	NA	RRG 2-3 years, reed 1-2 years, couch once early, lignum 1-2 years	After 4 years RRG declines and at 8 years dead
Fish	Declining	High	Intact floodplain and connected river	Spring flooding for flood dependent species	Short drying of creeks was natural, so long as refugial pools remain wet
Invertebrates	Declining	Moderate	Mosaic; little known about specific habitat associations	Frequently flooded (every 1-4 years) most productive and diverse communities	Dry 1-4 years most productive, > 10 years reduced biodiversity
Woodland birds	Declining	High	remnant woodland >36ha	c.f. vegetation and soil.	After 4 years RRG declines and at 8 years dead
Frogs	Declining	High	Varied	Unknown	Unknown
Carbon cycles	Declining	Moderate	Carbon levels linked to organic matter and vegetation communities, but specific relationships unknown	Frequently flooded (every 1-4 years) highest carbon concentrations	Dry 1-4 years highest carbon levels; dry > 10 years low carbon levels

3.2.4. Framing climate change adaptation within an objectives hierarchy

Loss of flooding due to river regulation is the key degrading factor in the declining resilience of the Macquarie Marshes wetland ecosystem, driving both ecological and social systems beyond viable thresholds, significantly increasing susceptibility to the impacts of climate change. As summarised (3.2.3), climate change in the Macquarie Marshes will probably primarily drive reduction in flooding volumes and frequencies. However, past impacts of water regulation on loss of flooding will likely continue to overshadow those projected through climate change. Given existing water entitlements to the Macquarie Marshes (146243ML general security and 3340ML supplementary), the likelihood of resilience to anticipated climate change is uncertain. The single primary adaptation for restoring the Macquarie Marshes ecosystem is the return of adequate environmental water needed to restore the short and moderate inter-flood intervals. This can be achieved through increased water entitlements for the environment or reductions in extractive share of flow through changes in legislation and policy. Achieving this within the next decade will likely buffer against existing 2030 climate change projections of increased temperature and reduced runoff. Intermediate adaptations through the removal of biophysical drivers such as buy-back, voluntary water sharing, and increased outlet capacity to increase environmental water volume aimed at eliminating inter floods interval larger than 2 to 4 years can have only a limited effect. True ecological restoration and resilience to long-term climate change can only come from changes of social institutions behaviours and amendments to the water sharing plans (Jenkins et al., 2011).

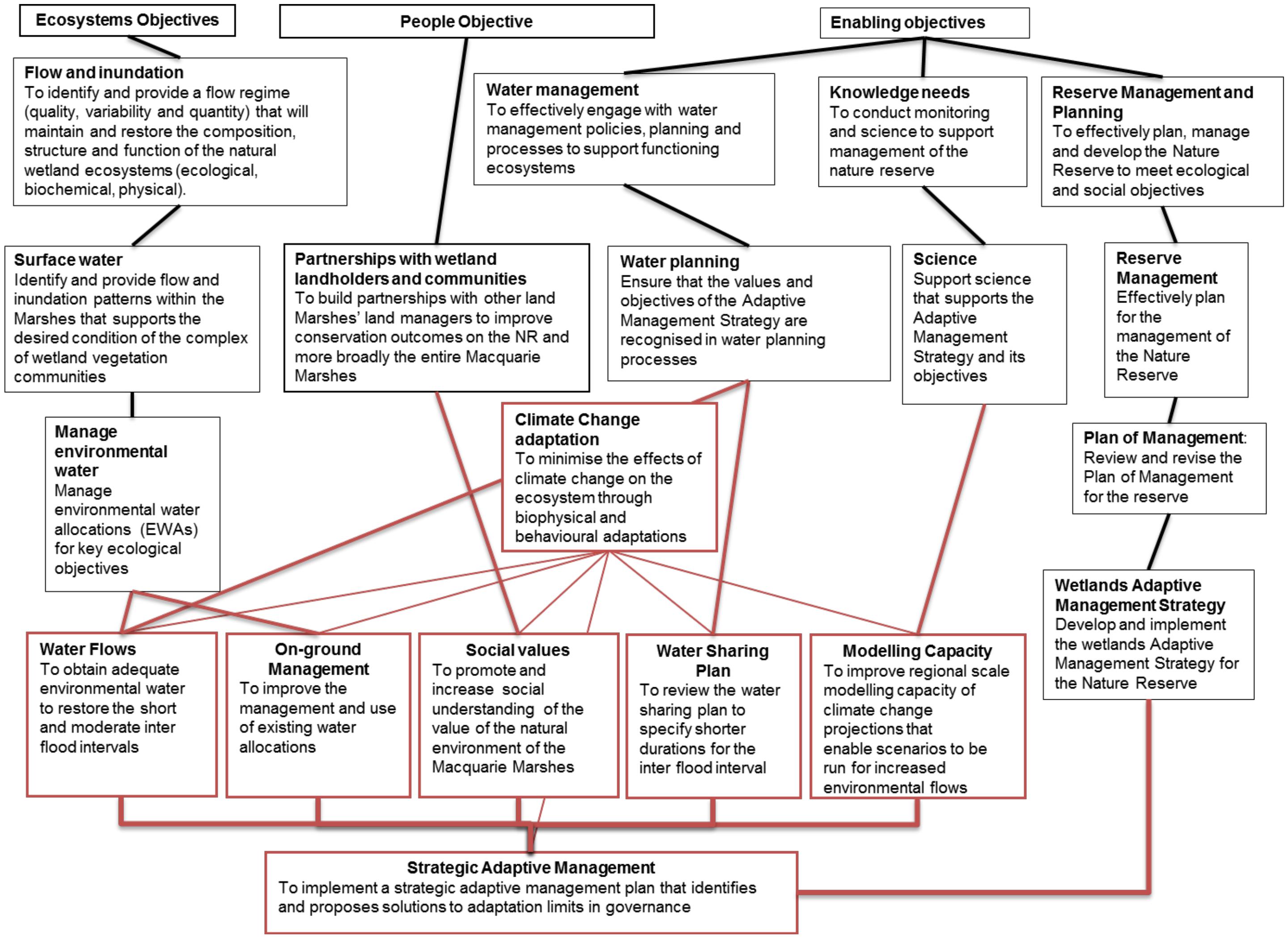
Presently, an explicit consideration of climate change adaptation strategies, within the developed objectives hierarchy, is lacking. Adaptation to climate change can be autonomous, physical, institutional/political, or through land management (Jenkins et al. (2011). Adaptations within the Macquarie Marshes Nature Reserve should aim to minimise the effects of climate change on the ecosystem through biophysical and behavioural adaptations.

Potential adaptations may include:

- **Water Flows**: obtaining adequate environmental water to restore the short and moderate inter flood intervals;
- **On-ground Management:** improving the management and use of existing water allocations as well as to maximise the effectiveness of treatment and abatement activities;
- **Social values:** promoting and increasing social understanding within the local and broader community of the value of the natural environment of the Macquarie Marshes;
- **Water Sharing Plan:** reviewing the water sharing plan to specify shorter durations for the inter flood intervals;
- **Modelling Capacity:** improving regional scale modelling capacity of climate change projections that enable maximising ecological returns on environmental flows; and
- **Strategic Adaptive Management:** implementing a strategic adaptive management with appropriate documentation that can be reviewed and used for decision-making.

Within the context of structured decision-making, climate change adaptation strategies should be linked to three of the four high level objectives identified for the Macquarie Marshes (Figure 9). Adaptation of water flows is achieved through management as well as policy and therefore should link both to ecosystem objectives under the management of environmental water for key ecological objectives as well as to the enabling objectives aimed to effectively engage with water management policies, planning, and processes to support functioning ecosystems. Adaptation through amendments to the water-sharing plan should also be lined under similar enabling and water sharing objectives. Promoting social understanding should link under the high-level people's objectives, focusing on building partnerships with local farmers and communities. Increasing modelling capacity can only be attained through the support of science under enabling objectives. Finally, the implementation of a strategic adaptive management plan falls naturally under the wetlands adaptive management strategy objectives within the high-level enabling objective.

Figure 17: Integration of climate change adaptation strategies within existing objectives hierarchy, presently developed by OEH.



Temporal hierarchy of adaptation

Interaction of existing challenges in the Macquarie Marshes nature reserve and Ramsar site along with projected climate change for the region suggest adaptation strategies are reliant on the time horizon for short and long-term management (Figure 18).

Under existing climatic conditions, the Macquarie Marshes have been severely impacted by river regulation, reducing flooding volumes, and extending the inter-flood intervals. Key ecological assets are experiencing extreme water duress leading to changes in the ecological character of the Ramsar site. Among the prominent and most chronicled changes, include observed degradation of semi-permanent vegetation and reduction in waterbirds breeding events. Ecosystem services have also diminished, namely in reduction of grazing productivity, affected areas reliant on livestock grazing.

Short-term strategies

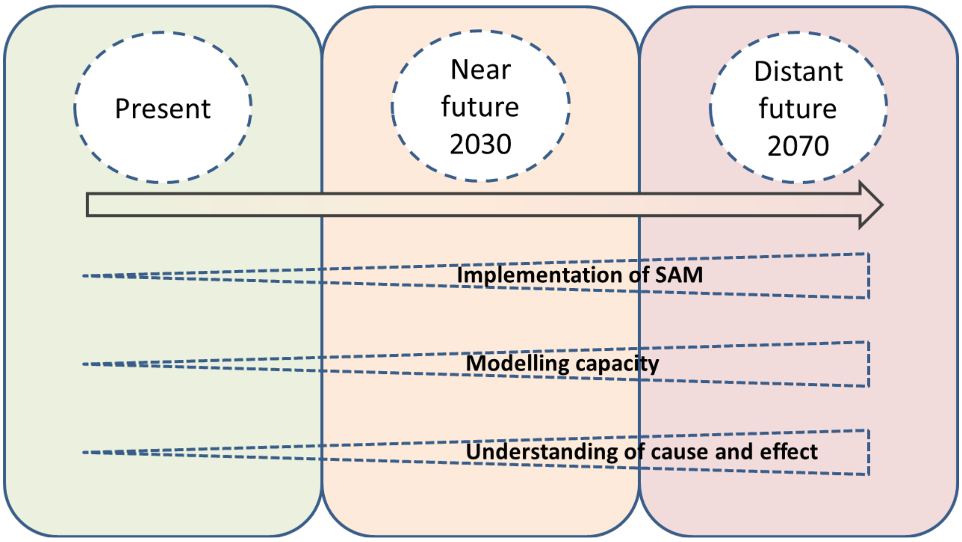
Given projected climate change for the near future (i.e., 2030), the main challenges facing the Macquarie Marshes will centre on effective management of water allocations operating within a heavily regulated system. Relatively small changes in climate will likely be eclipsed by the natural variation of the environment. For now, short-term management strategies will inevitably focus on reducing the dominant obstacles standing in the way of desired restoration targets. Avoiding identified thresholds of concern of ecological assets during inter-flood periods will enable managers to sustain the ecosystem or as a minimum to delay degradation. Reducing the inter-flood interval stands as one of the foremost obstacles that may be eased through buying back sufficient volumes of water and increasing the outlet capacity.

Implementing a strategic adaptive management approach requires that managers learn from ecological responses during inter and intra flooding periods. Improving hydrological modelling capacity and testing ecological responses to increased allocations of environmental flows will enhance development of adaptation strategies. This requires change in attitude towards ongoing quantitative monitoring, aimed at assessing the outcomes of taken management actions and continuously improving models of ecological cause-and-effect to future management scenarios.

Long-term strategies

Long term climate change projections (2070), imply increased changes to the floodplain, potentially surpassing those brought by river regulation. With no significant increase in water allocations, continued degradation of the Macquarie Marshes ecological indicators and social values is anticipated. Even with sophisticated adaptive water management strategies, developed in the short term, their success in achieving desired management objectives would be highly limited without changes to existing legislation and policy regarding water entitlements (Hannah et al. 2002; Scott et al. 2002; Moser and Ekstrom 2010). Changes in social institutional attitude and legislation that foster cooperation within and across jurisdictions, will ultimately be necessary to increase the capacity for adaptation (Cross et al., 2012).

Figure 18: Time horizon of adaptation strategies for the Macquarie Marshes.



3.3. Process model of the ecosystem

A critical component for improving adaptation for freshwater ecosystems, within the adaptive management framework, is to build a common understanding of system behaviour through a developed process model. Here we identified different wetland states and potential drivers related to water availability and climate change using two approaches. The first approach taken (3.3.1) relied on expect knowledge accumulated over many years with both management experience and scientific knowledge of in the Macquarie Marshes system, elicited through an expert workshop. The second approach (3.3.2 and 3.3.3) also employed a process model but built on data-driven statistical models to examine the response of key indicators of the Macquarie Marshes to inundation and flow patterns. We then integrated developed statistical models to form a cohesive process models for the ecosystem (3.3.4).

3.3.1. Expert judgment of ecological response of the Macquarie Marshes to alternative surface water management scenarios

Introduction

The Macquarie Marshes are currently managed for many key ecological assets impacted by drought conditions and water resource development (Kingsford and Thomas, 1995, Kingsford and Johnson, 1998, Ren et al., 2010, Roberts and Marston, 2011, Steinfeld and Kingsford, 2011, Thomas et al., 2011a). More recently, increased environmental flows have been purchased by the NSW and Australian Governments. There is uncertainty about long-term trajectories of climate change, thus decisions about how best to allocate water across the Marshes system to protect these assets in the long-term are also uncertain. A workshop was held 20-22nd February 2012 with experts with management and scientific experience in the Macquarie Marshes system (7.1.1). The aim was to elicit plausible models of ecological cause-and-effect for key assets of the Macquarie Marshes under alternative water management regimes and plausible climate change scenarios, to form the basis of a process model for the Macquarie Marshes.

The purpose of process models is to summarise the current understanding of system dynamics and the anticipated response of the system to management and climate change scenarios. The models capture the cause-and-effect processes that drive anticipated responses, the variables for assessing those responses, and explicitly identify uncertainties in current knowledge.

The process models can inform the Strategic Adaptive Management framework, currently being developed by NSW Office of Environment and Heritage and supported by researchers at the Australian Wetlands and Rivers Centre, University of New South Wales (Kingsford et al., 2011a, Kingsford and Biggs, 2012a), and funded by The National Climate Change Adaptation Research Facility.

The aim of the adaptive management framework is to develop a hierarchy of objectives, underpinned by a process model which captures the cause and effect relationships among variables in the Marshes. Such a Strategic Adaptive Management framework could provide a more flexible updateable tool for prioritisation of management actions for key assets and functions in the Macquarie Marshes, including the management of environmental flows. The framework is designed to clearly demonstrate the linkages between key values, objectives, management actions and monitoring. Outcomes of the workshop will also inform ongoing development of a quantitative process model within the broader adaptive management framework, which may include additional alternative water management regimes and assets.

Elicitation of expert judgement

Models are a critical component of adaptive management as they help represent our beliefs about ecosystem properties and dynamics, and project the consequences of how the system responds to management. Models in their most simple forms encompass people’s conceptual understanding of how a system works. People differ in perceptions of the merit of alternative management actions because they hold (Howard, 2007):

- different understandings of cause-and-effect
- different objectives or ecological priorities
- different attitudes to risk

Independently derived models of cause-and effect may illuminate controversy among scientists about how to best describe biophysical (or other) systems. This is especially true in risk management and adaptive management, where the behaviour of a system under extreme conditions or novel management is of interest (Burgman, 2005). Scientists refer to difficulties in model specification as model uncertainty. This uncertainty matters when it impacts on our ability to choose between management options. Adaptive management seeks to resolve this kind of model uncertainty over time through iterative updating of the plausibility of competing models.

A coarse distillation of behavioural and cognitive psychological research on expert opinion is that ‘experts know a lot but predict poorly’(Camerer and Johnson, 1991). Expert judgment can be compromised by overconfidence, motivational bias and a raft of psychological frailties associated with probabilistic reasoning (Kahneman and Tversky, 1984, Armstrong, 2001, Yaniv, 2004). Knowledge may involve configural rules and cues, of which a substantial proportion may be inaccurate. For example, fire experts have comprehensive knowledge of the physical determinants of fire behaviour, but predict the spread of fire poorly when variables such as wind direction and slope are in opposition (Lewandowsky and Kirsner, 2000).

While numerous approaches to expert elicitation have been developed for individual events or distributions, there are few formal methods for elicitation or representation of models of cause and effect (Hodgkinson et al., 2004). Any approach involves trade-offs among elicitation burden, inferential clarity and susceptibility to overconfidence.

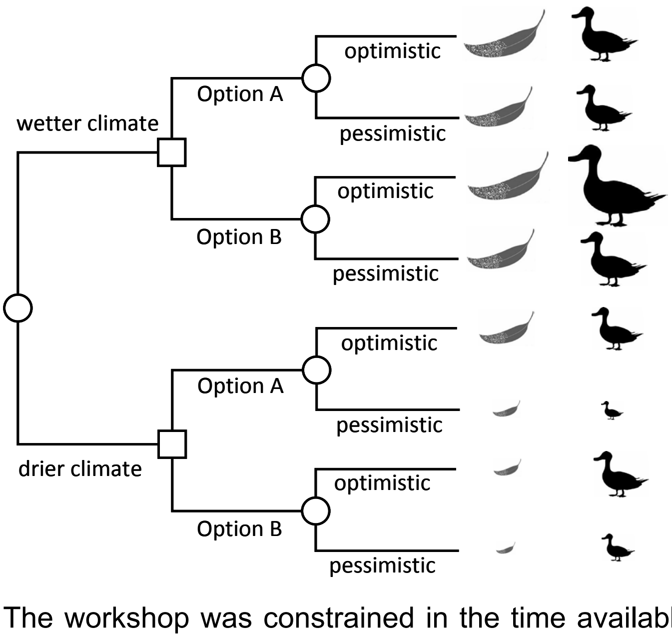
Methods

We used a similar procedure developed by Nadkarni and Shenoy (2004) to elicit cause-and-effect narratives for deriving conceptual models. It provides substantial inferential clarity while buffering against the psychological frailties of expert opinion through structured development of causal judgments.

The judgments underpinning a decision to manage the system one way or another are sketched as a logic tree (Figure 19), within the context of changes to climate. The aim of a logic tree is to provide a simple way of defining the decisions to be made. It can help tease out the cause and effect relationships that may vary across different people's understandings. Events that are beyond the decision-maker's control, such as climate change, are indicated by a circle (○), representing chance outcomes. Climate projections suggest temperatures may rise across the region (leading to increased evaporation and water temperatures), but projected changes in rainfall are highly uncertain. We can however ascribe a subjective estimate to the chance of things spilling one way or another.

The decision to manage water allocation under Option A or Option B can be controlled, as indicated by a square (□). The merit of Option A or Option B depends on future climate and the magnitude of the (uncertain) ecological pay-off. The pay-offs in Figure 1 include vegetation condition (leaf size, e.g. river red gum condition) and colonial waterbird breeding (duck size). The wisdom of going with Option A or Option B depends on probabilistic judgments of whether the future climate will be wetter or drier, whether optimistic or pessimistic payoffs will eventuate, and the value we place on vegetation versus colonial waterbird breeding. The cause-and-effect models developed at the workshop concentrated on best guess, optimistic and pessimistic predictions for ecological payoffs under candidate options and plausible climate change scenarios.

Figure 19: Logic tree summarising the main judgments needed to make a coherent decision on water allocation under uncertainty for vegetation condition (leaf size) and breeding of colonial waterbirds (duck size) in the Macquarie Marshes.



The workshop was constrained in the time available for eliciting expert judgments but we elicited cause and effect models for 3 climate change scenarios, 3 management options, and 4 ecological assets over a time horizon of 50 years. The full consequences of action (or inaction) may not be realised for decades. The time horizon of 50 years represents a reasonable compromise between ecological relevance and predictive capacity. We followed five steps, described in more detail below:

- Step 1. Develop alternative management options
- Step 2. Define four ecological assets and associated attributes
- Step 3. Predict return time of flood under each climate change scenario
- Step 4. Elicit cause-and-effect models
- Step 5. Assess management options

Step 1. Develop alternative management options

We first elicited management options from the participants. Within the constraints of water availability, the volume that flows to each of the following three areas is potentially under separate management control (see

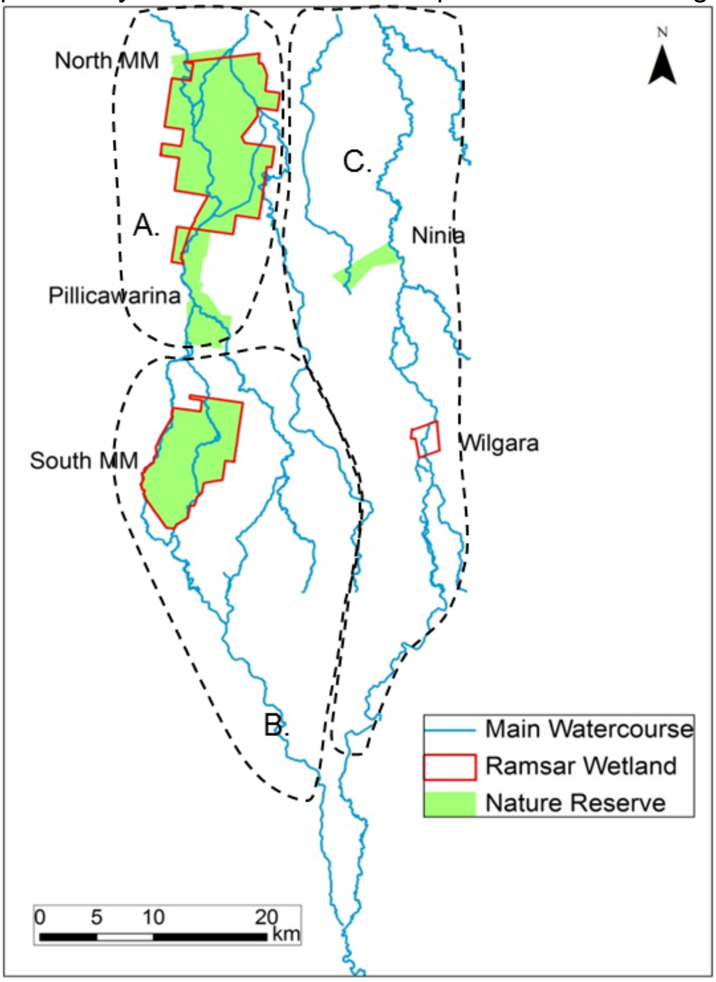


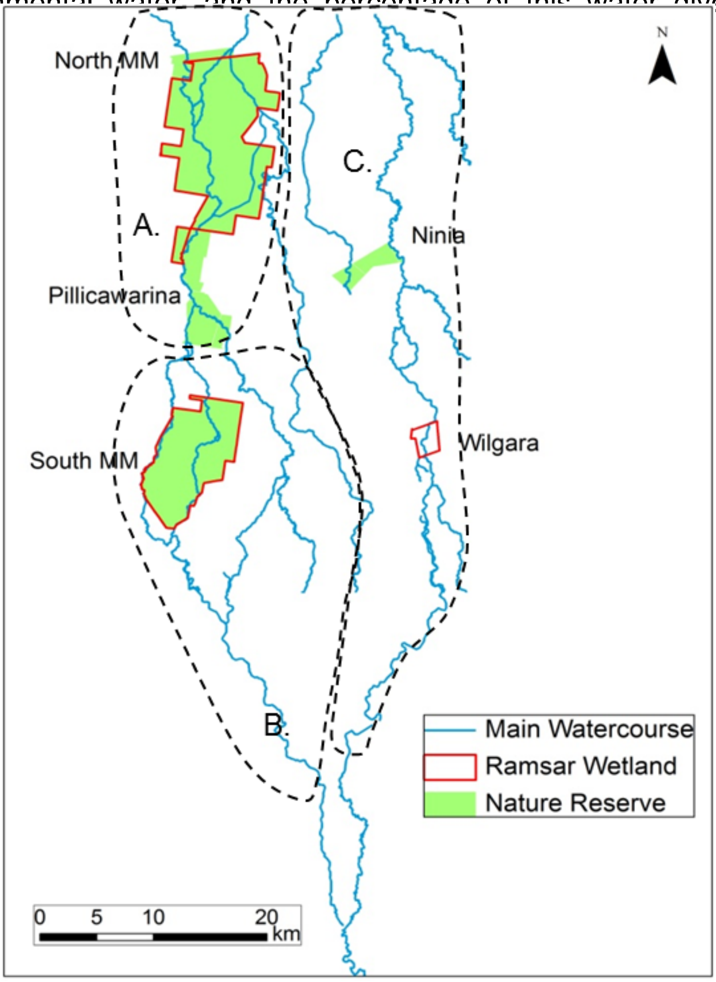
Figure 20):

(a) the northern section (on the west branch),

(b) the southern section (on the west branch)

(c) the eastern branch

The options explored at the workshop involved choosing the amount of licensed environmental water, and the percentage of this water diverted between the three



areas (

Figure 20), and whether or not environmental water is carried over for use in subsequent years. For the sake of clarity and simplicity, we assumed all options included *status quo* arrangements for managing invasive species and fire. There were three main management options used in the elicitation process (Table 12). These included different watering options. In developing and shortlisting these particular options, participants sought to assess the change in ecological payoff in circumstances where there may be less environmental water made available in adverse political circumstances (Option Less Water), or more made available under favourable circumstances (Option More Water) (see Table 12).

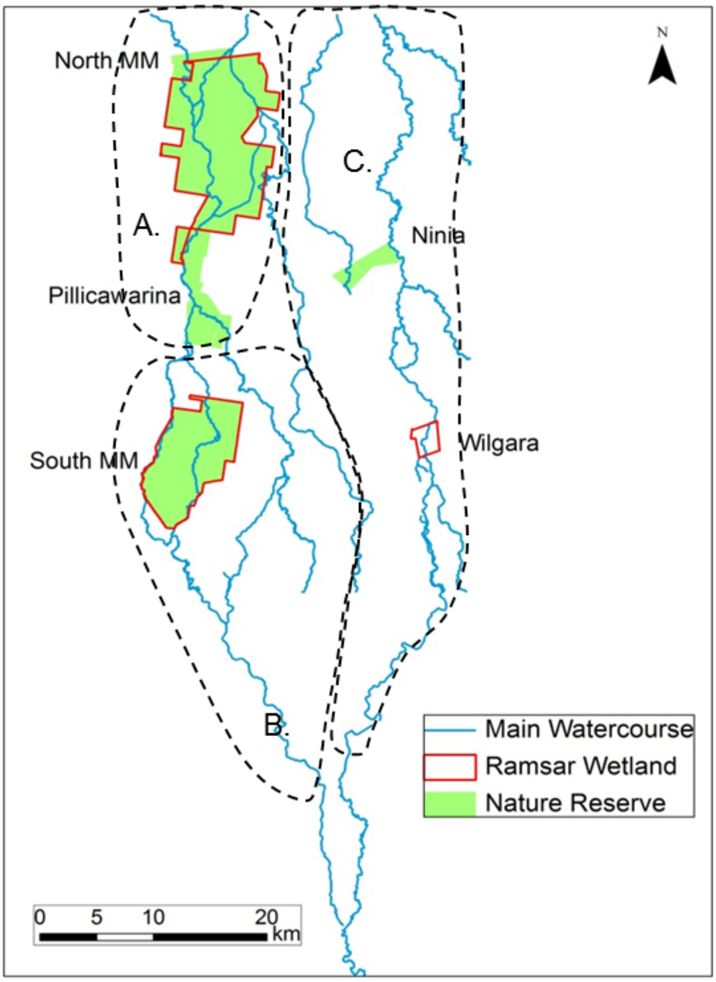


Figure 20: Major channels, nature reserves and Ramsar wetlands of the Macquarie Marshes, showing the three main areas, enclosed by dashed lines, for which management options were developed (A. – northern section on the west branch, B. southern section on the west branch, C. eastern section).)

Table 12: Three main management options shortlisted by workshop participants, which included the annual environmental water available and the potential diversion of this water to the three management areas, with the option of carryover. Note that the sum of allocations to the north, south, and east exceeds the total licensed water volume because it was assumed that about half the water allocated to the south flows on to the north, based on expert advice.

Option	**Environmental Water**[1]	**Water spilt**			**Carryover**
		North	South	East	
Less Water (L)	200 GL	50%	30%	20%	Yes
		130GL	60GL	45GL	
Business as Usual (B)	300 GL	35%	50%	15%	Yes
		180GL	150GL	45GL	
More Water (M)	500 GL	30%	45%	25%	Yes
		250GL	225GL	125GL	

[1]Represents the annual volume of licensed environmental water available if the main storages are full

Step 2. Define assets and attributes

We then developed a shortlist of key ecological assets (Table 13). A list of ecologically important assets for each area was first developed, which included the major vegetation communities within the Macquarie Marshes, and breeding of colonial waterbirds. We then examined how participants felt each asset would fare under the different management options. Those assets that showed substantial variation in belief about the response to management were then chosen as 'key assets', providing a sound basis for discriminating the merit of candidate management options. That is, although assets that vary little in their performance across options may be ecologically important, they are more or less redundant in assessment of *identified* options.

To estimate how the assets change over time, in relation to various management options and climate change scenarios, assets needed to be further defined according to a number of attributes (Table 14). Inherently, protection and management of key assets form the basis of the objectives, and we want to measure progress toward these. Attributes thus provide the performance measures. As such, we considered only attributes that were ecologically important, socially relevant, could be directly measured and were sensitive to the management options. For all attributes considered we estimated the range in values under 'status quo' conditions (Table 14). These estimates represented the initial extant state, and formed the starting point for the elicitation process. When defining the values of the attributes, we encouraged consideration of plausible bounds around best estimates to guard against overconfidence. For the remainder of the elicitation process, participants worked in small groups according to their particular interests and expertise in relation to the assets before coming back together to discuss their results.

Table 13 Coarse assessment of the performance of each management option within the three management areas, against each ecological asset on a four point scale of dots (zero = poor performance, three = good performance). Shortlisted assets (highlighted) include only those that varied across options by two or more points and were therefore considered sensitive to discrimination among management options.

Assets/Options	Less Water (L)	Business as Usual (B)	More Water (M)
North			
Black box woodland		••	•••
Red gum woodland	••	••	•••
Red gum forest	•••	•••	•••
Water couch	•••	•••	•••
Lignum	•••	•••	•••
Reeds	•••	•••	•••
Lagoons	•••	•••	•••
Waterbirds[a]	•	••	•••
South			
Red gum woodland	•	••	•••
Water couch	••	•••	•••
Reeds	•••	•••	•••
Lagoons	•	••	•••
Waterbirds	••	••	•••
East			
Black box woodland			••
Red gum woodland	•	•	•••
Water couch	••	••	•••
Lignum[b]	•	•	•••
Lagoons	••	••	••
Waterbirds			•••

[a]Waterbirds indicated breeding of colonial waterbirds.

[b]Lignum in the eastern branch was considered strongly positively correlated with breeding of colonial waterbirds and was therefore omitted from further analysis.

Table 14: Attributes for each ecological asset identified for use in elicitation process, with estimates of value range under status quo conditions.

Coolibah/Blackbox woodland	Red gum woodland	Lagoons	Waterbird breeding
Canopy health (average proportion of canopy with live foliage, NDVI). • Status quo (North): 50-80% • Status quo (East): 50-80%	Canopy health (average proportion of canopy with live foliage, NDVI) • Status quo (South): 20-40% • Status quo (East): 40-80%	Species richness of waterbirds over a wet/dry cycle • Status quo (South): 20-40 sp	Frequency of large successful breeding events for egrets (>20 000 nests) over a 10 year period • Status quo (North): 2-3 • Status quo (East): 0-1
Survival rate of large old trees (% per decade) • Status quo (North): 80-95% • Status quo (East): 80-95%	Survival rate of large old trees (% per decade) • Status quo (South): 70-90% • Status quo (East): 80-95%	Species richness (calling) of 'flow response' frogs • Status quo (South): 3-4	Frequency of medium successful breeding events for egrets (>2000 nests) over a 10 year period • Status quo (North): 3-4 • Status quo (East): 1-2
Proportional cover of terrestrial dry vegetation (semi-arid, native or exotic, incl dryland grasses and chenopods), on average over decade • Status quo (North): 50-80% • Status quo (East): 50-80%	Proportional cover of terrestrial dry vegetation (semi-arid, native or exotic, incl dryland grasses and chenopods), on average over decade • Status quo (South): 50-80% • Status quo (East): 40-70%	Abundance of invertebrates • Status quo (South): 800-2000 indiv/Litre	
Recruitment (yearly % area new seedlings, summed over decade eg. 2 events covering 60% area=120%) • Status quo (North): 5 - 10% • Status quo (East): 5 - 10%	Proportional cover of perennial vegetation (terrestrial damps, including Juncus, Rumex, Summer Warrego grass) • Status quo (South): 10-30% • Status quo (East): 20-40%		
	Recruitment (yearly % area new seedlings, summed over decade) • Status quo (South): 10-20% • Status quo (East): 10-30%		

Step 3. Predict return time of flood under each climate change scenario

We used predictions from the CSIRO of potential changes to flood indicators for 2030 under three plausible climate change scenarios (‘Dry’, ‘Mid’ and ‘Wet’) (Table 15). Using expert knowledge of participants, we established the current 50-year maximum return time of inundation for each of the identified ecological asset (Table 14). We then used climate change predictions to modify maximum return time of inundation so that they were relevant to the asset, area, and management option in question (Table 16). They were also extrapolated from 2030 to 2060, as participants elicited judgements over a 50-year time horizon.

Table 15: Predictions of flood indicators for 2030 under three plausible climate change states (dry, mid and wet) relative to current and historic regimes for the Macquarie River. Modelling assumed no further development in the catchment [Source: CSIRO (2008)]

Indicator	Historic	Current	% change from current		
			Future (dry)	Future (mid)	Future (wet)
Average period between winter–spring floods	2.2 yrs	4.7 yrs	24%	10%	-25%
Maximum period between winter–spring floods	7 yrs	15 yrs	20%	0%	0%
Average winter–spring flood volume per year	118 GL	75 GL	-38%	-16%	21%
Average winter–spring flood volume per event	278 GL	322 GL	-6%	-5%	5%

Indicator	Description
Average period between winter–spring floods	Average period (years) between winter–spring (1 June to 30 November) floods exceeding 200 GL volume at the Oxley gauge
Maximum period between	Maximum period (years) between winter–spring (1 June to 30

winter–spring floods	November) floods exceeding 200 GL volume at the Oxley gauge
Average winter–spring flood volume per year	Average annual volume above the 200 GL volume threshold at Oxley gauge between from 1 June and 30 November
Average winter–spring flood volume per event	Average event flow volume above the 200 GL volume threshold at Oxley gauge between 1 June and 30 November

Table 16: Predictions of the maximum return time of inundation 50 years hence, under three plausible climate change states (dry, mid and wet) in relation to key ecological assets, three management options, Less Water (L), Business as Usual (B) and More Water (M) and the three management areas, north (N), south (S) and east (E) in the Macquarie Marshes.

Asset/Area/Management Option	Max period between Winter-Spring floods (years)		
	'Dry' scenario	'Mid' Scenario	'Wet' scenario
Black box/N/L	25–40	25–40	25–40
Waterbirds/N/L	10–15	8–12	7–11
Black box/N/B	25–40	25–40	20–35
Waterbirds/N/B	10–15	8–12	7–11
Black box/N/M	17–31	17–31	10–20
Waterbirds/N/M	9–12	6–10	5–9
Red gum/S/L	10–18	8–15	7–13
Lagoons/S/L	7–24	6–20	5–18
Red gum/S/B	6–12	5–10	4–9
Lagoons/S/B	5–16	4–13	4–12
Red gum/S/M	3–8	3–6	3–5
Lagoons/S/M	2–10	2–8	2–7
Black box/E/L	30–45	30–45	30–45
Red gum/E/L	10–20	8–15	6–12
Waterbirds/E/L	10–15	8–12	7–11
Black box/E/B	30–45	30–45	25–40
Red gum/E/B	10–20	8–15	6–12
Waterbirds/E/B	10–15	8–12	7–11

Black box/E/M	22–36	18–30	15–25
Red gum/E/M	5–10	4–8	3–7
Waterbirds/E/M	7–12	6–10	4–9

Step 4. Elicit cause-and-effect models

Under each management option, for each shortlisted ecological asset, we focussed on a transition from a starting point representing the initial extant state (i.e. the 'status quo', Figure 21) to plausible states that may be observed after 50 years (i.e. the year 2060) of management (blue boxes on the right hand side of Figure 21). We required participants to develop models, independently in groups according to their area of expertise, and to then cross-examine perspectives and review judgments in the light of fresh insights. We avoided uninformative complexity in causal narratives by constraining the number of variables (determinants/threats) that participants could include in their models to five (Özesmi and Özesmi 2004).

Participants were first asked to provide their best estimate, bounded by optimistic and pessimistic judgments about how each of the attributes would change for a single management option (Business as Usual), under one climate change scenario (Mid). Participants were also asked to identify the processes driving those changes (Figure 21 determinant/threat), and the direction in which those processes were changing (Figure 21, descriptor). The full results for all ecological assets, options, and areas are provided in 7.1.2.

Given time constraints, we were unable to elicit changes in attributes under each management option and climate change scenario. Instead, we fixed the ranges specified for each of the attributes under the optimistic, pessimistic, and best-guess estimates, and asked participants to estimate the probability of each of those estimates occurring under the other management options and climate change scenarios.

Table 17 shows an example of how probabilistic judgments varied under each scenario for lagoons in the South. Full results are provided in 7.1.3.

Figure 21: Example of judgements elicited from participants (Lagoons South). The probability of transitioning from an initial (status quo) state to three plausible future states in 50 years was elicited for each asset, for each management option and climate change scenario. The three future states encompass the most likely expected outcome, bounded by optimistic and pessimistic plausible outcomes, given uncertainties about the ecosystem response. Yellow boxes contain the processes (determinants/threats) that summarise the key factors that influence outcomes.

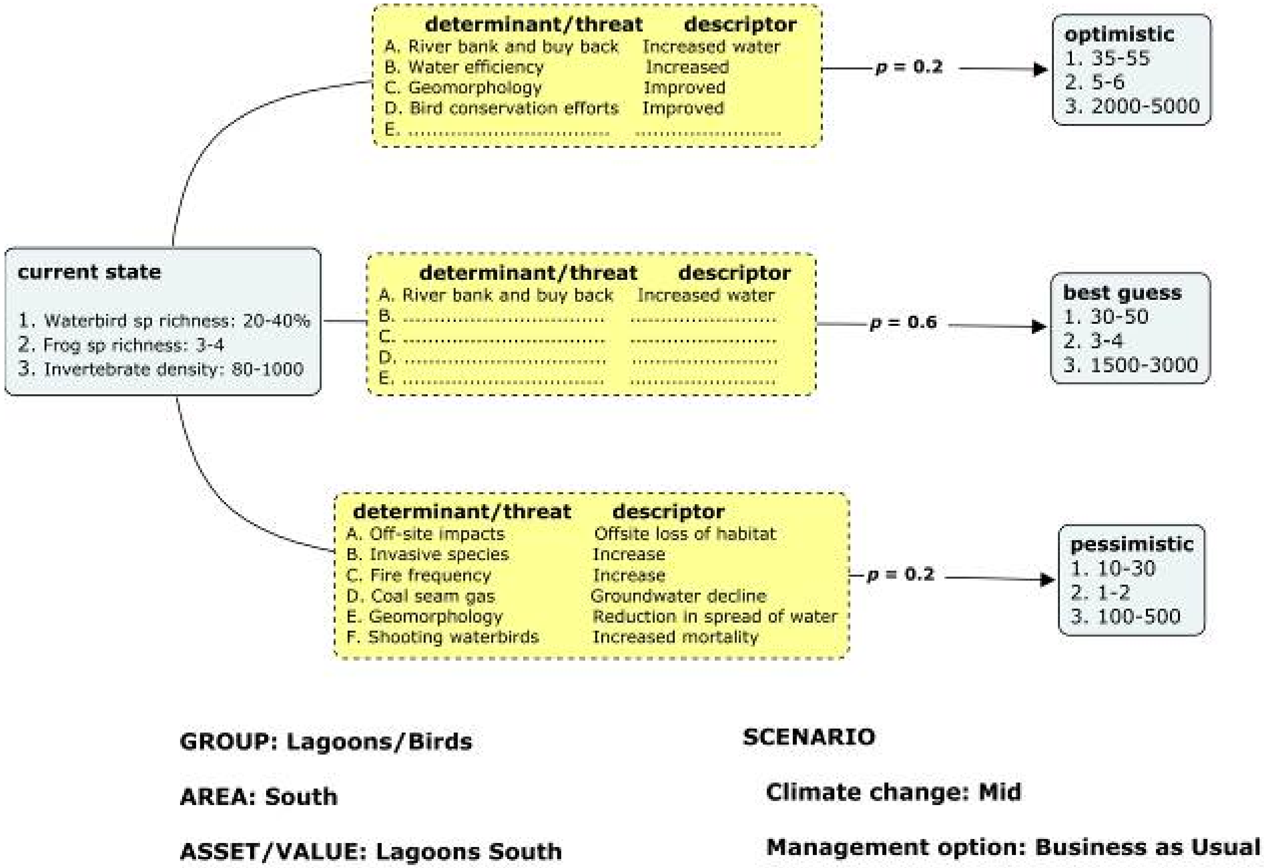


Table 17: Probability of each estimate (optimistic, pessimistic, and best-guess) occurring under each management option and climate change scenario for 'Lagoons South'. All probabilistic judgments used the optimistic, pessimistic, and best guess estimates for change in ecological attributes shown in Figure 21. The probabilistic judgments shown in Figure 21 are shaded.

Climate change scenario	Management option	Estimate	Probability
dry	Less Water	optimistic	0.05
		best guess	0.25
		pessimistic	0.70
mid	Less Water	optimistic	0.05
		best guess	0.35
		pessimistic	0.60
wet	Less Water	optimistic	0.10
		best guess	0.40
		pessimistic	0.50
dry	Business as Usual	optimistic	0.15
		best guess	0.55
		pessimistic	0.30
mid	Business as Usual	optimistic	0.20
		best guess	0.60
		pessimistic	0.20
wet	Business as Usual	optimistic	0.20
		best guess	0.60
		pessimistic	0.20
dry	More Water	optimistic	0.70
		best guess	0.20
		pessimistic	0.10
mid	More Water	optimistic	0.80
		best guess	0.15
		pessimistic	0.05
wet	More Water	optimistic	0.80
		best guess	0.15
		pessimistic	0.05

Each group was also asked to provide estimates of the probability that each of the three climate change scenarios described by CSIRO (2008) would indeed eventuate (Table 18).

Table 18: Group estimates of the probability that each climate change scenario will eventuate.

Climate scenario	Group A	Group B	Group C	Average
Dry	0.15	0.33	0.60	0.36
Mid	0.70	0.33	0.30	0.44
Wet	0.15	0.33	0.10	0.19

Step 5. Assess management options

Development of plausible cause-and effect models was the focus of the workshop. To make coherent management decisions, predictive models need to be integrated with trade-offs describing the extent to which we value anticipated change in the state of one asset against that of others. One of the participants assigned scores to optimistic, best guess and pessimistic state estimates for each asset (7.1.4). The score given to any state reflects both *its importance* and *the range* of predictions across alternatives to the participant (Steele et al. 2009). A common mistake is to weigh only on the basis of importance (Keeney 2002). To make the range of states salient we used a modified version of the swing weights method (von Winterfeldt and Edwards 1986).

In this method, the decision-maker first considers pessimistic states for all key assets and is asked which single asset they would preferentially 'swing' from the pessimistic state to the 'optimistic' state. That asset is given the highest rank and its optimistic state is assigned a score of 100 on an arbitrary scale representing value. The decision-maker then sequentially works through the remaining assets, assigning ranks according to preference and assigning scores according to the extent to which they value each state relative to a score of 100 (7.1.4).

The expected value of each management option was obtained using simple weighted summation, whereby the contribution any single asset made to the overall performance of an option was weighed by the probability of each state being realised under each climate change scenario (7.1.3) and the probability of each climate change scenario eventuating (Table 7). Unsurprisingly, the 'More Water' option (500GL) performed best, followed by the 'Business as Usual' (300GL) and 'Less Water' (200GL) option (Figure 22). The ecological assets that were most sensitive to the options considered included red gum woodland in the south and lagoons in the south, because of the high value assigned to these assets (7.1.4) and a belief embedded in cause-and-effect models (7.1.2) that the ecological condition of these assets would be especially dependent on large flows. The contribution of colonial waterbird breeding (east and north), and red gum woodland in the east varied little across the options. Black-box/Coolibah woodlands had only a minor contribution to aggregate performance because of the small weight they carried in value judgments (7.1.4).

The summary results in Figure 22 are disaggregated for each of the three climate change scenarios in Figure 23. The wet scenario leads to marginally better conditions than the mid scenario, which in turn is substantially better than the dry scenario. Qualitatively, the observations made above are again evident. Within each scenario, the rank order of the overall performance of alternatives is preserved. Relative performance of the options is again dominated by the response of red gum woodlands and lagoons in the south, with most other assets more or less invariant across management options. A notable exception is red gum woodland in the east, which under the dry scenario, performs distinctly better under the 500GL 'More Water' option than the other two options.

It is intuitive that in an analysis that explored only ecological response, the order of favoured management options corresponded with the amount of environmental water licensed. A more considered management decision would also take into account other factors, such as cost, feasibility, and broader socio-economic values. To incorporate these other values and make trade-offs would require a more comprehensive structured decision making exercise, in which the information from this workshop could be built upon.

Figure 22: The merit of the three management options aggregated over key ecological assets and weighted according to average probabilistic estimates for the three climate change scenarios. The *y*-axis represents expected value on a unitless scale.

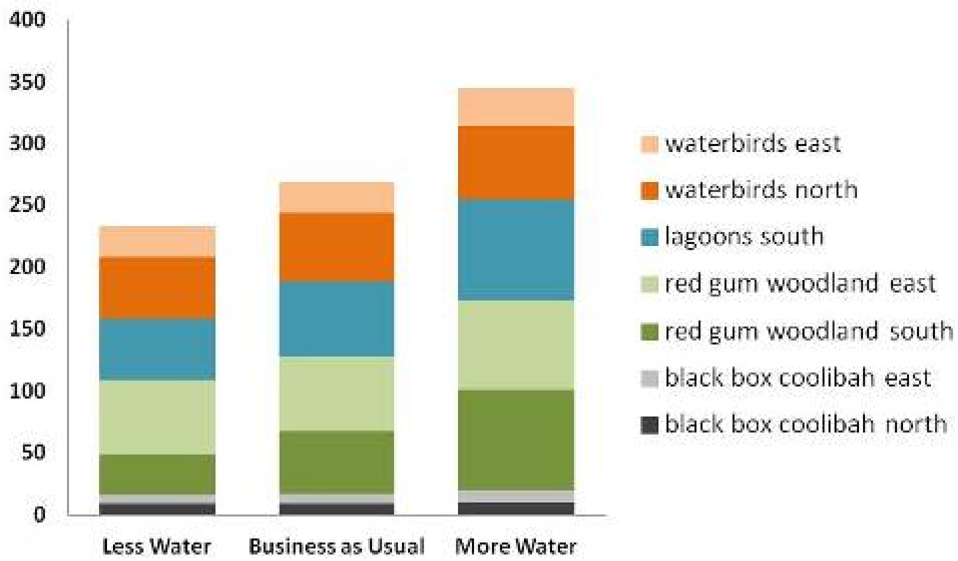
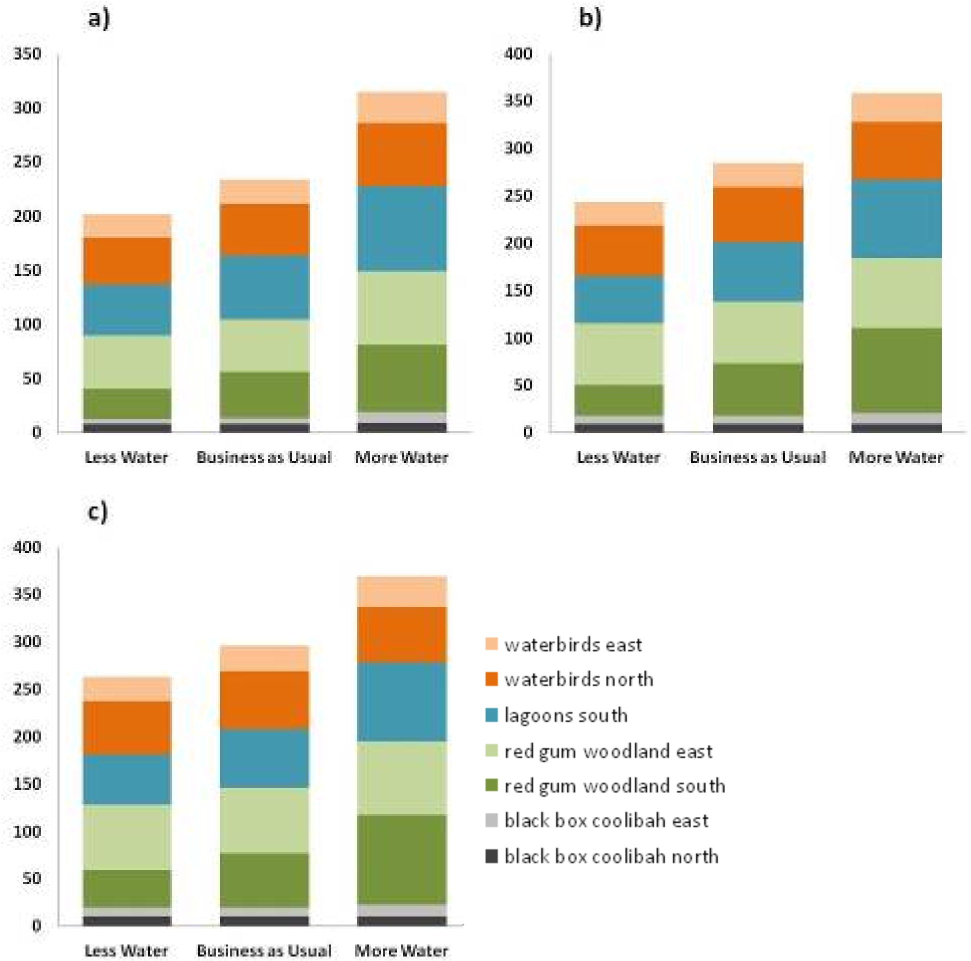


Figure 23: The merit of the three management options aggregated over key ecological assets under the (a) dry, (b) mid, and (c) wet climate change scenarios. The *y*-axes represent expected value on a unitless scale.



Conclusions

Workshop outcomes sketch a coarse decision analysis for a complex problem. While the analysis provides context for how predictive models can be utilised in decision-making, the primary goal of the workshop was elicitation of plausible models of cause and effect. Outcomes of the elicitation exercises conducted at the workshop are provided (7.1.2-4). These outcomes form a sound basis for extending, and formalising models to inform future management. Even in their current form, the draft models for Black box/Coolibah woodland, River red gum woodland, Lagoons and breeding of colonial waterbirds provide a basis for linking future management decisions to cause and effect processes. The attributes point to logical priorities for monitoring outcomes, although the actual variables monitored are likely to require further refinement when costs, feasibility, and other assets of concern are fully considered.

A major motivation for employing an expert elicitation is to establish immediate interim results when expert knowledge is the only source of information (Borsuk 2004). Expert elicitation can also help identify the most influential drivers of an ecosystem. Frequently, expert knowledge is regarded as subjective compared to that derived from empirical data. However, empirical data may harbour considerable biases, inadequacies, and errors in study design, collection, and transcription. In reality, expert knowledge and empirical data exist on a continuum of subjectivity and may vary in accuracy depending on the object of concern (Martin et al., 2012). The outcomes produced in this workshop only provide an initial step in establishing ecological cause-and-effect for key assets of the Macquarie Marshes under alternative water management regimes and plausible climate change scenarios. Essential to the adaptive management framework, these estimates should be updated as new empirical knowledge accrues. Bayesian methods are especially favoured as they allow prior information from either empirical data or expert knowledge can be incorporated (McCarthy, 2007). They also have the ability to deal with a mix of data sources, be built with stakeholders, and are presented graphically, thus facilitating communication. The Bayesian format allows expected outcomes of management to be updated as ecological data accumulates and climate change projections become more accurate, and will give progressively improved guidance on the most appropriate management options to achieve specified goals.

3.3.2. Maximising colonial waterbirds breeding events, using identified ecological thresholds and environmental flow management.

Introduction

Increased demand for freshwater has severely degraded the world's river and wetlands ecosystems (Lemly et al., 2000, Millennium Ecosystem Assessment, 2005, Vörösmarty et al., 2010). Over the course of the 20th century, more than 50% of the world's wetlands have already been lost (Millennium Ecosystem Assessment, 2005). Wetland biodiversity loss continues unabated with mounting global pressures facing freshwater aquatic ecosystems (Butchart et al., 2010). These come from multiple direct drivers, increasing the likelihood of nonlinear changes to ecosystems of increasing severity and expense (Folke et al., 2002). For example, thresholds of eutrophication, caused by excess inputs of nutrients, can produce cascading ecosystem changes and collapse (Carpenter et al., 1999, Carpenter, 2005). Primary indirect drivers of wetland degradation are linked to human population growth and increasing economic development, affecting infrastructure development, land conversion, water withdrawal, pollution, overharvesting and overexploitation, and the introduction of invasive species (Gibbs, 2000). Understanding the main drivers of ecosystem change and shortlisting conservation targets must be the first step for formalising an ecological model depicting the key ecological components and the underlying processes of cause and effect (Maddox et al., 2001). The model should represent the important biological processes in the ecosystem, identifying the key attributes of the ecosystem (i.e., indicators) that managers should monitor (Kingsford, 2011).

River regulation has fragmented hydrological and ecological processes (Nilsson et al., 2005), often severing or restricting connectivity to rivers and wetlands (Lemly et al., 2000, Kingsford et al., 2006). (Arthington et al., 2009, Poff and Zimmerman, 2010, Arthington, 2012). This can be achieved by recovery of flow regimes, alteration of dam operations, management of protected areas, and effective governance and adaptive management (Kingsford et al., 2011a). For heavily regulated systems, recovery of flow regimes by increasing environmental flows is a crucial conservation objective for many dependant freshwater ecosystems, affected by river regulation (Arthington et al., 2006). Flow regimes of regulated rivers are managed, largely through the operation of dam storage and release (Kingsford, 2000, Stewardson and Gippel, 2003, Harman and Stewardson, 2005). Conservation-management strategies focussed on alteration of dam operations can improve environmental outcomes for rivers and wetlands (Palmer et al., 2008, Pittock and Hartmann, 2011). Modelling techniques linking hydrology with ecological responses are an invaluable tool for robust decision-making of environmental flows. Choice of ecological indicator is critical for conservation management, as failure to detect thresholds in an ecosystem can significantly alter decision making and ignore important information (Eiswerth and Haney, 2001). Colonial waterbirds are among the most conspicuous of wetland animals and are useful indicators of wetland ecological health (Paillisson et al., 2002, Kingsford and Auld, 2005a, Stolen et al., 2005). Flow regimes are a key driver of waterbird community composition, abundance, and breeding (Kingsford et al., 1999, Kingsford and Auld, 2005a, Kingsford and Porter, 2009, Brandis et al., 2011, Wen et al., 2011, Arthur et al., 2012). Flow regimes and inundation patterns influence availability and accessibility of habitat, resources, and breeding sites (Green and Robins, 1993, Clausen, 2000, Guillemain et al., 2000). Successful monitoring and management of colonial waterbirds can deliver robust decision-making under mounting anthropogenic perturbations and accelerated climate change as well as for measuring rehabilitation efforts with environmental flows (Kingsford and Auld, 2005a).

The Macquarie Marshes are an extensive, diverse and dynamic wetland system that covers an area of approximately 200,000 ha (Thomas et al., 2011a), including the Macquarie Marshes Nature Reserve of about 20,000 ha (NPWS, 2012), listed as a Ramsar site in 1986 (OEH, 2012c). Variability of flooding frequency form a complex mosaic of swamps, lagoons, channels, and gilgaied floodplain, inundated by the Macquarie River and its distributary streams. The Macquarie Marshes incorporate extensive areas of reed swamp (*Phragmites australis*), river red gum (*Eucalyptus camaldulensis*), black box (*E. largiflorens*), coolibah (*E. coolabah*), lignum (*Muehlenbeckia florulenta*), and water couch grasslands (*Aspalum distichum*) (Paijmans, 1981, Shelly, 2005b), providing important habitat for many species of flora and fauna (Kingsford and Auld, 2005a). The Macquarie Marshes also provide ecosystem services supporting highly productive grazing and cropping industries and hold important cultural and heritage values for indigenous and non-indigenous people (OEH, 2010). They are managed for many ecological assets (OEH, 2012c), notably as the most important in Australia for waterbird feeding and breeding, in terms of population sizes, colony sizes, number of species, and frequency of breeding (Kingsford and Thomas, 1995, Kingsford and Auld, 2005a). Colonial waterbirds congregate and form breeding colonies in response to large flows that inundate the Macquarie Marshes floodplain (Kingsford and Johnson, 1998). Minimum flows required to trigger a breeding event range between 180 and 300GL over the spring period (Kingsford and Auld, 2005a). Smaller flows often do not support successful colonial breeding, but do support breeding by other water-dependant species.

The systems' extreme natural variation in annual inflows (12- 1,300 GL, measured at Marbone) imposes a boom and bust environment for its fauna and flora. However, river regulation and modification of the landscape over the past 50 years have disrupted the natural cycles of flood and drought, accelerating deterioration of the ecosystem (Kingsford and Thomas, 1995). Since construction of Burrendong Dam in 1967, the Macquarie Marshes experienced a significant reduction in moderate to high flows, an increase in the average period between large flows and a reduction in the average volume of these events (CSIRO, 2008c). In the early 1990s, the system received less than half their natural inflow (Kingsford and Thomas, 1995, Kingsford and Johnson, 1998). Consequently, inundation area, frequency, and duration all significantly declined (Thomas et al., 2011a). Changes in flow and inundation regimes have severe implications for the many ecological assets of the Macquarie Marshes including waterbirds (Kingsford and Thomas, 1995, Kingsford and Johnson, 1998, Kingsford and Auld, 2005a), fish (Puckridge et al., 2000), invertebrates (Jenkins and Boulton, 2007) and vegetation (Brock et al., 2003, Thomas et al., 2010a). Restoring and maintaining critical ecological functions are vital to improve the health and resilience of ecosystems, ensuring ecological, social, and cultural values are protected.

Acquisition of environmental water entitlements by the state and federal governments in the past two decades in the Murray-Darling Basin reached 2,105,000ML by 2011 (presently: 146243ML general security and 3340ML supplementary in the Macquarie River) has necessitated the formalisation of strategic planning of environmental water allocation (MDBA, 2012b, OEH, 2012d, SEWPAC, 2012). With considerable uncertainty regarding rainfall and temperature changes due to developing climate change (CSIRO, 2008c, Jenkins et al., 2011), decisions also remain uncertain on how best to allocate water across the Macquarie Marshes to protect these ecological assets in the long-term. Here, we explored alternative water management strategies and identified maximal strategies for successful long-term management of colonial waterbirds and the ecosystem as a whole. This was achieved by analysing fluctuations in breeding abundances of ten colonial waterbird species over the past quarter-century (1986-2010). We linked waterbird ecological response, as breeding abundances (number of nests), to water availability, identifying clear ecological thresholds using Bayesian logistic regression models. Using modelled ecological response, we constructed a spatially explicit Bayesian Belief Network (BBN) for an intuitive decision-making framework for conservation management of breeding waterbirds.

Colonially nesting waterbirds

Large flooding triggers colonial breeding of as many as 75,000 waterbirds (Kingsford and Johnson 1998). Of all the waterbirds that breed in the Macquarie Marshes, colonial nesting species are the most prominent, producing long-term estimates (25 years, 1986–2010) of breeding colony sizes (Kingsford and Johnson 1998). We relied on ground surveys during the breeding season (September–November) where number of pairs of breeding birds or nests were estimated (Kingsford and Johnson 1998). We examined colonial waterbird breeding sizes for ten species, occurring in the largest numbers (Kingsford and Johnson, 1998; Kingsford and Thomas 1995; Kingsford and Auld 2005). Waterbird species included great egret (GE - *Ardea alba*), intermediate egret (IE - *A. intermedia*), little egret (LE - *Egretta garzetta*), cattle egret (CE - *Bubulcus* rufous), night heron (NHI - *Nycticorax caledonicus*), glossy ibis (GI - *Plegadis falcinellus*), Australian white ibis (WHI - *Threskiornis mollucca*), straw-necked ibis (SNI - *Threskiornis spinicollis*), little pied cormorant (LPC - *Microcarbo melanoleucos*) and little black cormorant (LBC - *Phalacrocorax sulcirostris*). Breeding occurred across 16 colonies (Figure 24). As the system enables water and ecological management of two distinct areas, we stratified colonies and subsequent analysis to matching management areas: north & south (9 and 1 colonies) and east (six colonies) (Figure 24).

As we were interested in identifying the transition probabilities between non-breeding to breeding events, we modelled the binary response of each colonial waterbird species' breeding event, as a function of river flows. We used a Bayesian approach to generate a sample from the posterior distribution of a logistic regression model using a random walk Metropolis algorithm. We used R (R Development Core Team, 2012) and functions within the MCMCpack library (Martin et al., 2011). Unlike frequentist methods, Bayesian methods treat parameters as random variables with a given likelihood function and fixed data. Under this model, $y_i \sim$ Bernoulli(π_i) for observations i =1, . . . , n with inverse-link function:

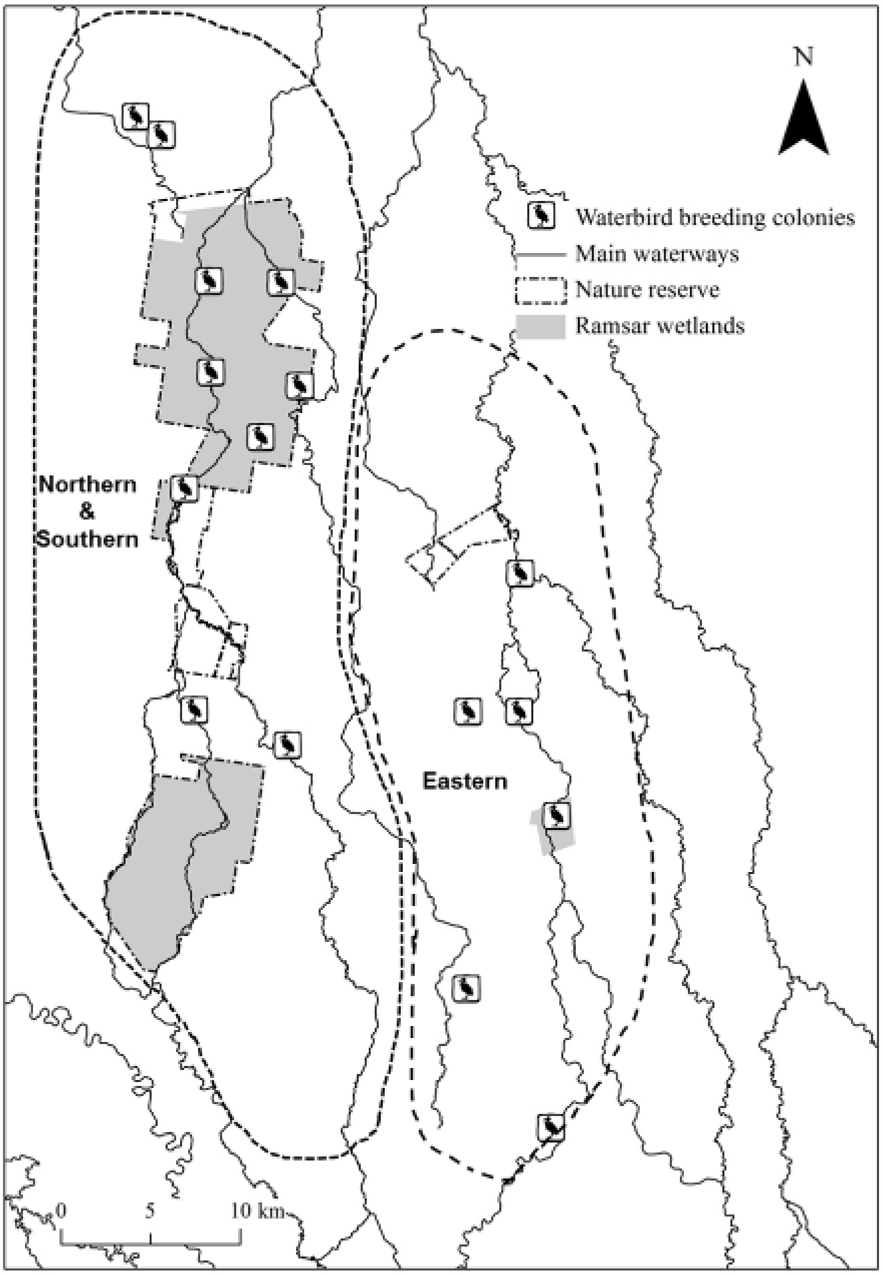
$$\pi_i = \frac{e^{(x_i'\beta)}}{(1 + e^{(x_i'\beta)})}$$

and a multivariate normal prior on beta:

$\beta \sim N(b_0, B_0^{-1})$

Then posterior inference was based on 10,000 Markov Chain Monte Carlo iterations after 1,000 burn-in iterations.

Figure 24: Sixteen waterbird breeding colonies in the Macquarie Marshes, showing the main creeks and rivers, the Nature Reserve and Ramsar wetlands (Nature Reserve, private area Wilgara, 500ha). Dashed labelled polygons represent the two management regions (Northern and Southern, Eastern).



Modelling water flows

Flows to the Macquarie Marshes come primarily from the Macquarie River fed by the major tributary rivers: Fish, Turon, Cudgegong, Bell, Little and Talbragar Rivers. Major dams regulate flows to the Macquarie Marshes: Windamere Dam (368GL) and Burrendong Dam (1,188GL plus 475GL flood storage). There are considerable losses before flows reach the Macquarie Marshes, due to water abstraction for irrigated agriculture, transmission losses and distributary creeks. The Macquarie River bifurcates after Marebone weir into the main channel of the Macquarie River and Marebone Break (OEH, 2012c). To estimate total flows entering the Macquarie Marshes and reaching the waterbird colonies, we obtained hydrological data between 1986 and 2011 from NSW's Government WaterInfo website for Marebone Weir and Marebone Break (http://waterinfo.nsw.gov.au).

We examined the effects of five environmental flow management scenarios on the variability of flows to the Macquarie Marshes and waterbird breeding. Scenarios were designed to achieve a minimum flow target (100, 200, 300, 400, or 500GL between July and December) at Marebone. Environmental flow entitlements were fixed for all strategies (equivalent to 400 GL of general security, including planned environmental water), but the timing of releases from the dam varied to achieve the minimum flow target. Environmental flows were released in pulses to enhance unregulated flows during the winter-spring breeding season and increase variability of dam releases (Kingsford and Auld, 2005a). Releases were triggered from the dam on the 1st August, if cumulative flows at Marebone (from 1st July) were below the environmental flow target. Releases rose and receded over 90 days, until the target was met or the environmental water account was depleted. All scenarios were based on statutory water management rules (NSW Government, 2002, NSW Government, 2003). We contrasted these scenarios with a tributary strategy simulated an immediate release of environmental flows, triggered by tributary flows. Finally, we examined the actual recorded flows at Marebone (1986-2011) under existing management strategy operating within the regulated system.

We simulated annual flows at Marebone (1900 – 2010; water year: July – June) at a daily time step for each strategy using coupled hydrological models. Dam and tributary inflows were simulated using a rainfall-driven Integrated Quality and Quantity Model (IQQM; (Simons et al., 1996) based on observed rainfall at 15 stations in the upper catchment (BOM, 2012), gap-filled and extended where necessary. Dam inflow data were input into an Environmental Water Allocation Simulator with Hydrology (eWASH; (Steinfeld, 2012)) that simulated allocations and their management according to strategies. We assumed current water management rules (NSW Government, 2003). Simulated dam releases were subject to gains and losses due to water abstraction, transmission and unregulated flows from major tributaries (Bell and Talbragar Rivers) between Burrendong Dam and Marebone. Simulated flows at Marebone were validated against observed data (waterinfoNSW, 2012).

Bayesian belief network

We constructed a Bayesian Belief Network (BBN) using the software package, Netica (NORSYS, 2011). This was a graphical model representing the key factors of a system (nodes) and their conditional dependencies (Varis, 1997, Korb and Nicholson, 2004, Jensen and Nielsen, 2007). Within the BBN, dependent or 'child node' (i.e., colonial waterbird breeding) were connected with direct links to 'parent node' (i.e., water flows). The network was then populated with conditional probability tables (CPTs), associated between each child and parent node. We populated CPTs using state transition probabilities, derived from the logistic regression models for each colonial waterbird species. The Netica software updates network belief by finding the marginal posterior probability for each node. In BBN analysis, prior probability is the likelihood that an input parameter is in a given state (e.g., frequency distribution of total annual flows). Conditional probability is the likelihood of the state of a parameter (e.g., breeding), given the states of input parameters (e.g., total annual spring flow). Posterior probability is the likelihood that some parameter will be in particular state, given the input parameters and the conditional probabilities. The BBN model assumes that conditional probabilities are independent and that prior probabilities are Dirichlet functions (Spiegelhalter et al., 1993): continuous and bounded between 0 and 1 (Castillo et al., 1997) and a multi-state extension of the beta distribution.

Results

The Macquarie Marshes were characterised by large temporal fluctuations in water flows, resulting in colonial waterbird breeding events with large flows (Figure 25). Over the past 25 years, total annual spring flows (July-Dec) ranged between ~20 and ~850GL (average 253GL±239 SD). Five years exhibited large flows >500GL, four > 250GL, while the remainder (16 years) had average flows of 94GL ± 62 SD. Concurrently, there were 15 breeding events across the Macquarie Marshes for the ten monitored species (maximum ~75,000, average ~14,000±24,700 SD). Four years were characterised as large breeding events (>20,000), three medium (<10,000), while the remaining breeding events averaged 2,495±1,948 SD birds. Straw-necked ibis and Intermediate Egret were the most numerous breeding species in the Macquarie Marshes (maximum 60,000 and 21,500, respectively). Conversely, the cattle egret, little black cormorant, and little pied cormorant) were the least numerous (maximum 190, 675, and 682 respectively). Together, the three ibis species were three times more abundant compared to the four egret species. Associated with this, the more abundant species were also more likely to from a breeding colony ranging from seven to 12 breeding events in the past 25 years.

A clear relationship existed between flooding events and colonial waterbirds breeding responses to in the Macquarie Marshes, both in frequencies and total abundances (Figure 25), with a strong linear relationship for flows over 200GL (R^2=0.71, F=17.5, p<0.01). Medium breeding events (>10,000-50,000) were only triggered when total spring flows were greater than 300GL (n=8) while large breeding events (>50,000) were triggered when total spring flows were greater than 600GL (n=4). When total spring flows were <200GL, absence of breeding was more frequent (n=10) but did occasionally support small breeding events (n=5, average 3,349). In addition to flooding events, breeding waterbirds depended on particular vegetation types for nesting (Table 19). The diversity of vegetation types found in the Macquarie Marshes promotes spatially varying, species-specific, patterns of nesting sites but despite this, traditional sites were used (Figure 24). Waterbird colonies found in reed-dominated vegetation supported larger breeding events (average 4,286), followed by reed and lignum vegetation (average 1,494). Generally, colonies in sites with different vegetation types supported a larger number of species (maximum 10 species).

Figure 25: Total annual spring flows (July-December) at Marebone (black line), along with total waterbird breeding abundances (white bars), 1986-2010.

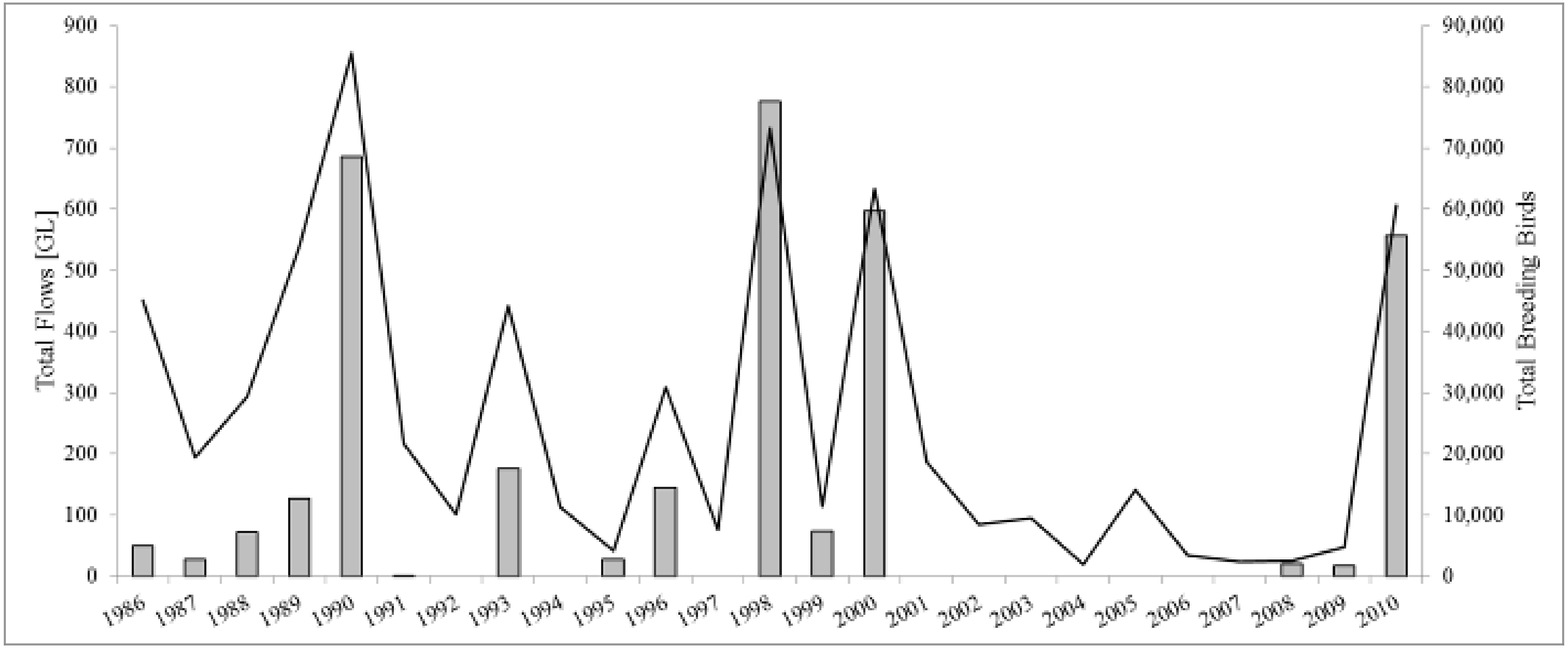


Table 19: Sixteen traditional colony sites, their dominant structural nesting vegetation, breeding colonial species and estimates of colony size when there was breeding within the Macquarie Marshes, 1986- 2010.

Colony	Vegetation[2]	Species[1]										Section	Mean ±SD	Max
		SNI	WHI	GLI	IE	GE	CE	LE	LBC	LPC	NH			
LoPC	RRG				■	■					■	East	144±705.5	3600
Oxley	RRG				■			■	■	■	■	East	374±1371.1	6800
Stanley	RRG				■						■	East	24±86.2	400
Terrigal 1	Reed, lignum and RRG	■	■	■	■	■	■	■	■	■	■	East	1157±3319.6	16000
Terrigal 2	Reed, lignum and RRG	■	■	■	■						■	East	445±1674.1	8125
Terrigal 3	RRG										■	East	100±489.9	2500
Bora 1	RRG		■		■	■	■	■	■	■		North	1728±3993	20300
Ginghet 2	Reed, lignum and RRG				■	■	■	■	■	■		North	288±991.3	4200
Ginghet 3	RRG				■	■	■	■	■	■	■	North	186.4±634.2	2510
Hunts	RRG				■							North	274.6±708.7	3190
Jblock	Reed and Lignum	■										North	120±430.8	2000
Loudens	Reed	■	■	■	■			■			■	North	501.2±1253.2	5400
Macquarie	Reed, lignum and RRG	■	■						■	■	■	North	31.1±93.4	450
Zoo	Reed and Lignum	■	■	■								North	2986.6±8158.9	37100
Bulgeraga	RRG	■	■									South	373±1222.5	5900
Monkeygar	Reed	■	■	■								South	4674±9194.3	36300

[1] Species abbreviations: IE – Intermediate egret, LE – Lesser egret, CE – Cattle egret, GE - Great egret, LBC – Little black cormorant, LPC – Little pied cormorant, NH – Night Heron, SNI – Straw neck ibis, GLI – Glossy ibis, WHI – Australian white ibis.

[2] RRG - River red gum woodland.

Breeding Thresholds

Average flows required for achieving a 0.5 breeding probability across the Macquarie Marshes was 333GL ± 187SD, while achieving a 0.9 breeding probability required 546GL±227SD. Clear thresholds emerged for triggering breeding events in all ten species but these varied among species (Figure 26a-c and Table 20). Across the entire Macquarie Marshes, three species (IE, WHI, and SNI) displayed a sharp threshold response between 100GL and 250GL total annual spring (July-December) flows. These had a breeding probability of 0.5 when flows were greater than 180GL and a 0.9 probability of breeding with flows over 350GL (Table 20). The remaining species (excluding CE) had a probability greater than 0.5 of breeding when total annual spring (July-December) flows exceeded 400GL. Cattle egret was the least likely to breed, with a 0.5 probability for breeding only with flows over 850GL. A 0.9 probability of breeding for the six species (IE, GLI, WHI, SNI, NH, and GE) was achieved with flows greater than 550GL. LBC, LPC, and LE required extremely large flows (810,870, 845GL, respectively) for a 0.9 probability of breeding.

Similar patterns emerged for the northern and southern section (Table 20 and Figure 27). Average flows required for achieving a 0.5 breeding probability in the northern and southern section was 347GL±189SD, while achieving a 0.9 breeding probability required 569GL±227SD. Of flows that triggered breeding, relatively small flows (<200GL) achieved a 0.5 breeding probability for three species (IE, WHI, SNI), while the remainder (excluding CE) had a 0.5 breeding probability with flows over 405GL. Similarly, IE, SNI, and WHI had a 0.9 breeding probability with flows greater than 330, 300, 300GL, respectively. GLI, NH, and GE reached a 0.9 probability of breeding with flows greater than 465, 660, and 520GL, respectively (Table 20). Overall, triggering a breeding event required higher flows for species in the eastern part of the Macquarie Marshes compared to those in the combined northern and southern section ($t=7.07$, $df=18$, $p<0.001$). Average flow required to achieve a 0.5 breeding probability in the eastern section was 702GL ± 142SD, while achieving a 0.9 breeding probability was only possible for IE and NH, requiring 630GL and 860GL, respectively. While IE required flows greater than 380GL for a 0.5 probability of breeding, the remainder required considerable flows (Table 20).

Figure 26: Breeding probabilities across the entire Macquarie Marshes for (a) four species of egret (intermediate egret (IE) Great Egret (GE), Cattle Egret (CE), Little Egret (LE)), (b) three species of ibis (Glossy Ibis (GLI), Australian White Ibis (WHI), Straw-necked Ibis (SNI)), and (c) Rufous Night Heron (NH), Little Pied Cormorant (LPC), Little Black Cormorant (LBC) in relation to increasing water flows to the Macquarie Marshes measured at Marebone, estimated using Bayesian logit model.

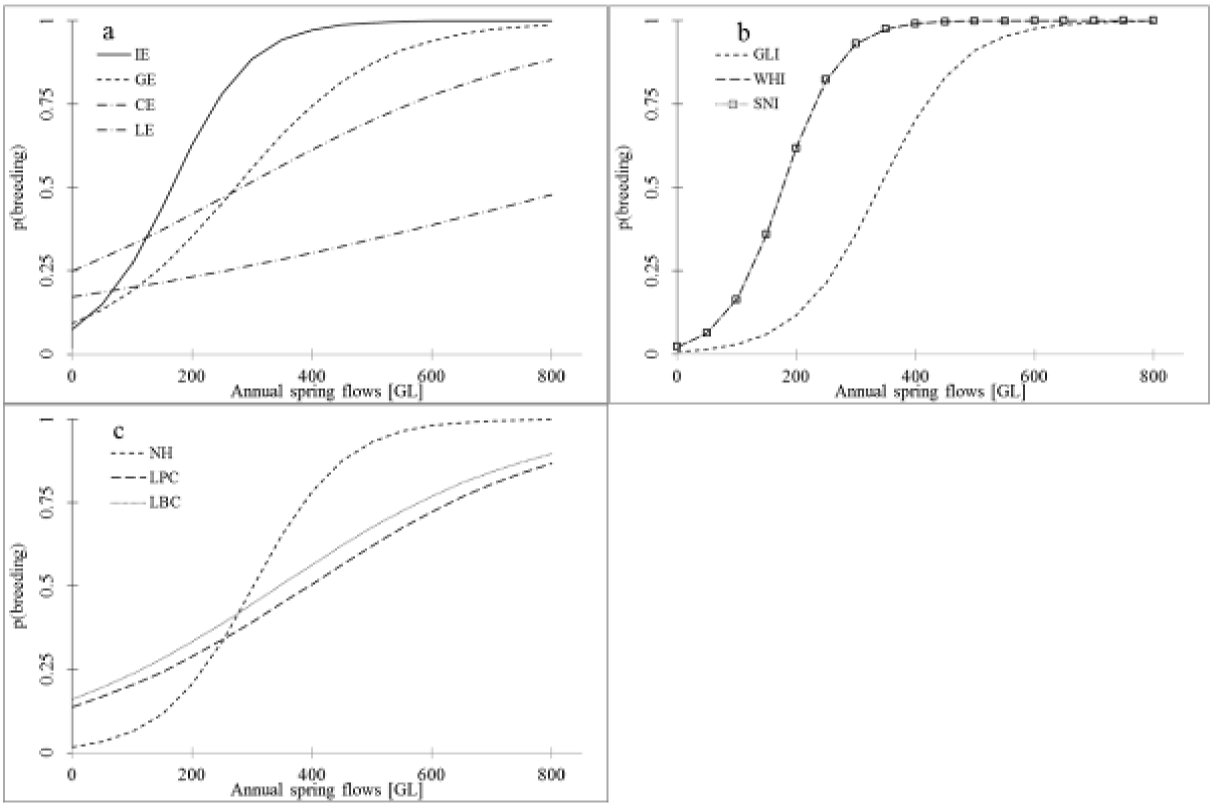


Figure 27: Breeding probabilities within the two management sections (Northern & Southern and Eastern) for (a) four species of egret (intermediate egret (IE) Great Egret (GE), Cattle Egret (CE), Little Egret (LE)), (b) three species of ibis (Glossy Ibis (GLI), Australian White Ibis (WHI), Straw-necked Ibis (SNI)), and (c) Rufous Night Heron (NH), Little Pied Cormorant (LPC), Little Black Cormorant (LBC) in relation to increasing water flows to the Macquarie Marshes measured at Marebone, estimated using Bayesian logit model.

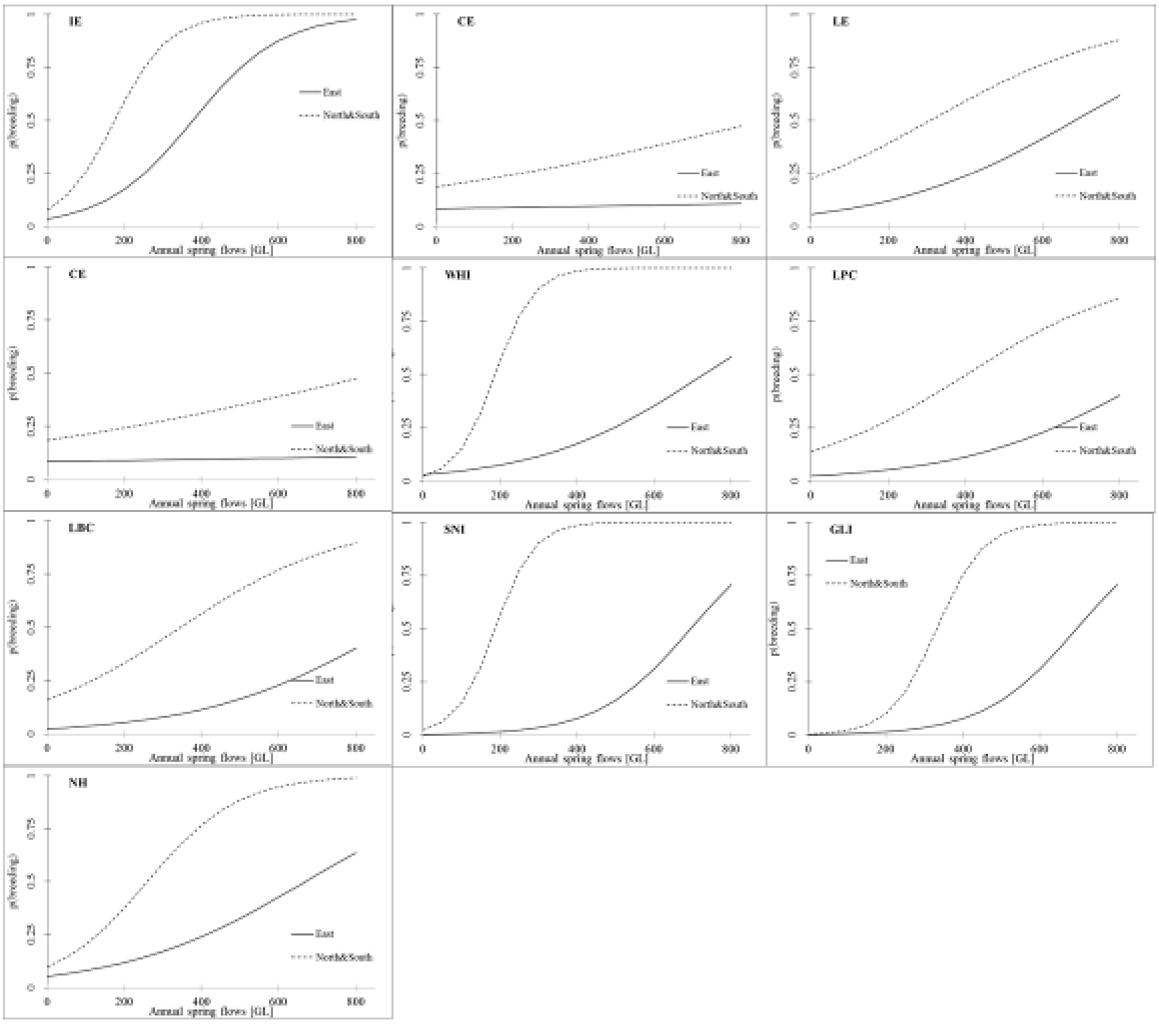


Table 20: Bayesian logistic model parameters fitted for each species across the Macquarie Marshes and within each of the two management areas along with total annual spring flows required to obtain a 0.5 and 0.9 probability of triggering a breeding event

Section / Species	Entire Macquarie Marshes			East			North & South		
	β±SD	Intercept ±SD	Flow P0.5\P0.9	β±SD	Intercept ±SD	Flow P0.5\P0.9	β±SD	Intercept ±SD	Flow P0.5\P0.9
IE	-2.505±1.054	0.015±0.006	170\315	0.009±0.003	-3.312±1.129	380\630	0.014±0.006	-2.485±1.023	175\330
GLI	-4.912±1.788	0.014±0.005	340\495	0.008±0.004	-5.831±2.458	700\na	0.017±0.006	-5.523±2.079	335\465
WHI	-3.738±1.422	0.021±0.008	180\285	0.005±0.003	-3.434±1.238	730\na	0.02±0.008	-3.708±1.377	190\300
SNI	-3.738±1.422	0.021±0.008	180\285	0.008±0.004	-5.831±2.458	700\na	0.02±0.008	-3.708±1.377	190\300
LBC	-1.645±0.744	0.005±0.002	350\810	0.004±0.003	-3.687±1.414	895\na	0.005±0.002	-1.645±0.744	350\810
LPC	-1.835±0.793	0.005±0.002	395\870	0.004±0.003	-3.687±1.414	895\na	0.005±0.002	-1.819±0.757	405\890
NH	-4.011±1.412	0.013±0.005	305\470	0.011±0.005	-7.322±3.267	660\860	0.008±0.003	-3.1±1.084	390\660
GE	-2.287±0.864	0.008±0.003	275\535	0.004±0.002	-2.855±1.06	675\na	0.009±0.003	-2.211±0.871	260\520
CE	-1.567±0.749	0.002±0.002	850\na	0±0.003	-2.381±1.039	na\na	0.002±0.002	-1.473±0.737	860\na
LE	-1.102±0.65	0.004±0.002	285\845	0.004±0.002	-2.805±1.013	685\na	0.004±0.002	-1.235±0.681	310\850

Optimising management outcomes

The constructed BBN provided an intuitive presentation of breeding probabilities, given a specific Probability Density Function (PDF) of flows (Figure 28). Under the historic regulated PDF (1986-2011) and current water management strategy, average probability of breeding across the Macquarie Marshes was 0.36±0.09SD. Within each management area, breeding probabilities in the northern and southern section was 0.35±0.09SD. Species most likely to form breeding colonies were IE (p=0.45), SNI (p=0.4), WHI (p=0.4), and LE (p=0.39). The least likely species to form breeding colonies included NH (p=0.15) and GLI (p=0.15). The eastern section harboured considerably lower overall breeding probabilities, with an average probability of 0.09±0.06SD. In the eastern section, IE, LE, and GE were the most likely to form breeding colonies (p=0.24, 0.14, 0.14, respectively) while the remainder had probabilities lower than 0.1 (average 0.6 ± 0.03SD).

Management to different target volumes of environmental flows affected overall and specific breeding probabilities (Figure 29). Management of water for attaining medium to large flooding events (300-500GL) significantly increased breeding probabilities compared to the regulated historic probabilities. The largest improvement in breeding occurred when environmental flows were managed to a total annual spring flow target of 400GL (T400, Figure 29). Improvement was significantly greater than that observed under the regulated historic flow record (t=-3.07, df=18, p=0.007). When release threshold was set to 500GL, most species experienced a reduction in breeding probabilities. A small proportion of flows actually reaching the 500GL threshold and a larger proportion of flows under 300GL drove the reduction in breeding probabilities (Figure 30). The likelihood of overall breeding events occurring for all ten colonial waterbirds increased from a regulated historic average of 0.36±0.09SD to 0.53±0.14SD, an improvement of 47.5%±18.7SD. Most notably, breeding likelihood increased for GLI (83%), NH (72%), SNI (54%), and WHI (54%). In contrast, the least favourable ecological outcomes were obtained when environmental flows were released immediately, triggered by tributary flows (i.e., Tributary, average 0.31±0.07SD). Consistently, when environmental flows were managed for total annual flows of 400GL, the northern and southern section presented significantly higher probabilities of waterbird breeding events compared with those in the eastern section (average = 0.52±0.14SD and 0.16±0.09SD, t=6.55, df=18, p<0.001).

Figure 28: Bayesian belief network (BBN) constructed for colonial waterbirds across the Macquarie Marshes. The network provides specific breeding probabilities for each species for a given flow (Total annual spring flow [GL]) as well as overall breeding probabilities for any given management strategy (Historical flows (1986-2011), strategies aimed to achieve a minimum flow target of 100, 200, 300, 400, or 500GL between July and December, and a tributary strategy simulating an immediate release of environmental flows, triggered by tributary flows). Individual species breeding responses (acronyms detailed in Table 19) are provided for each section (Northern & Southern and Eastern).

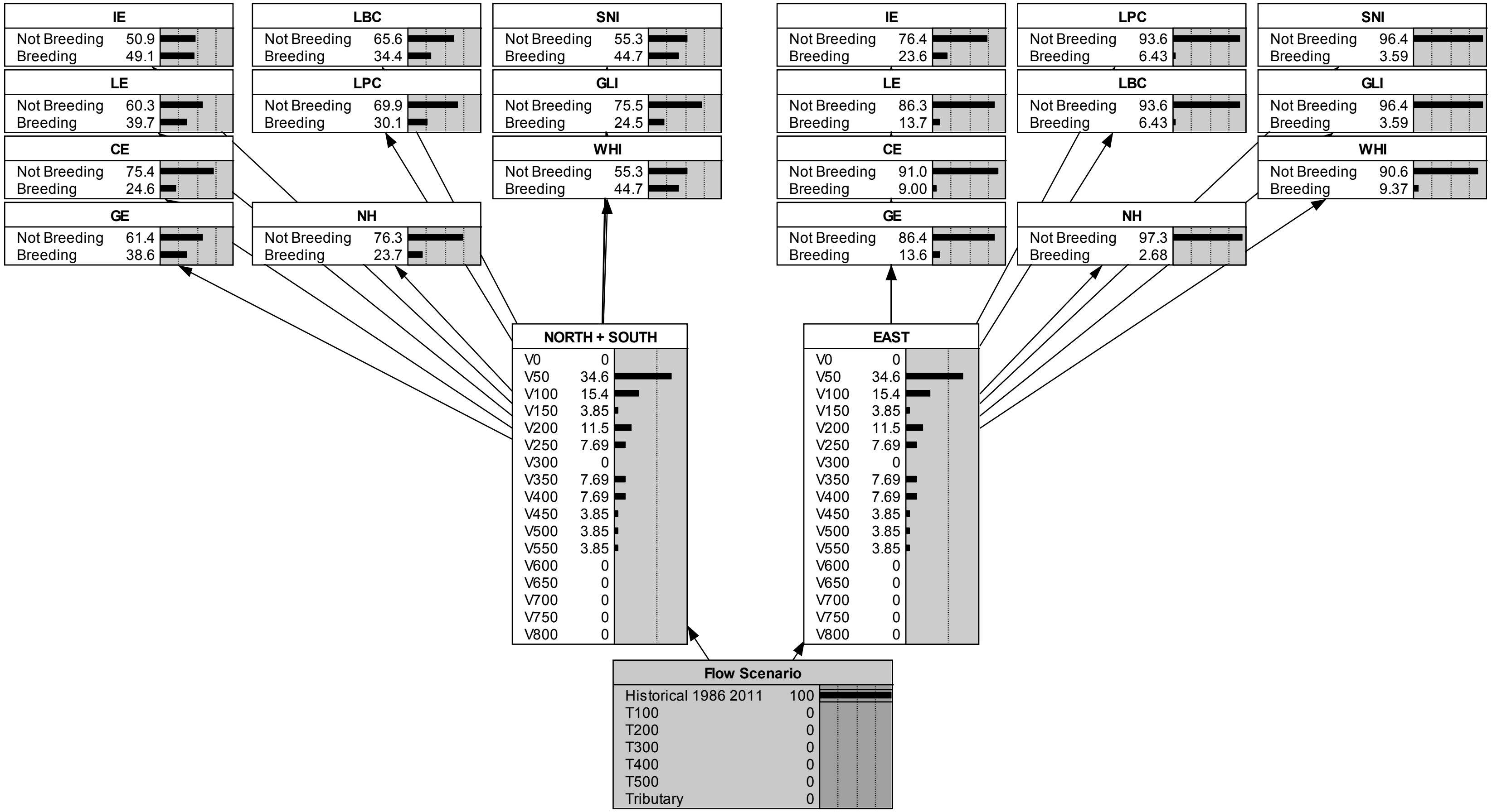


Figure 29: Overall breeding probability for colonial waterbirds when employing different environmental water allocation strategies: historical flows (1986-2011), five strategies aimed to achieve a minimum flow target of 100, 200, 300, 400, or 500GL between July and December, and a tributary strategy simulating an immediate release of environmental flows, triggered by tributary flows).

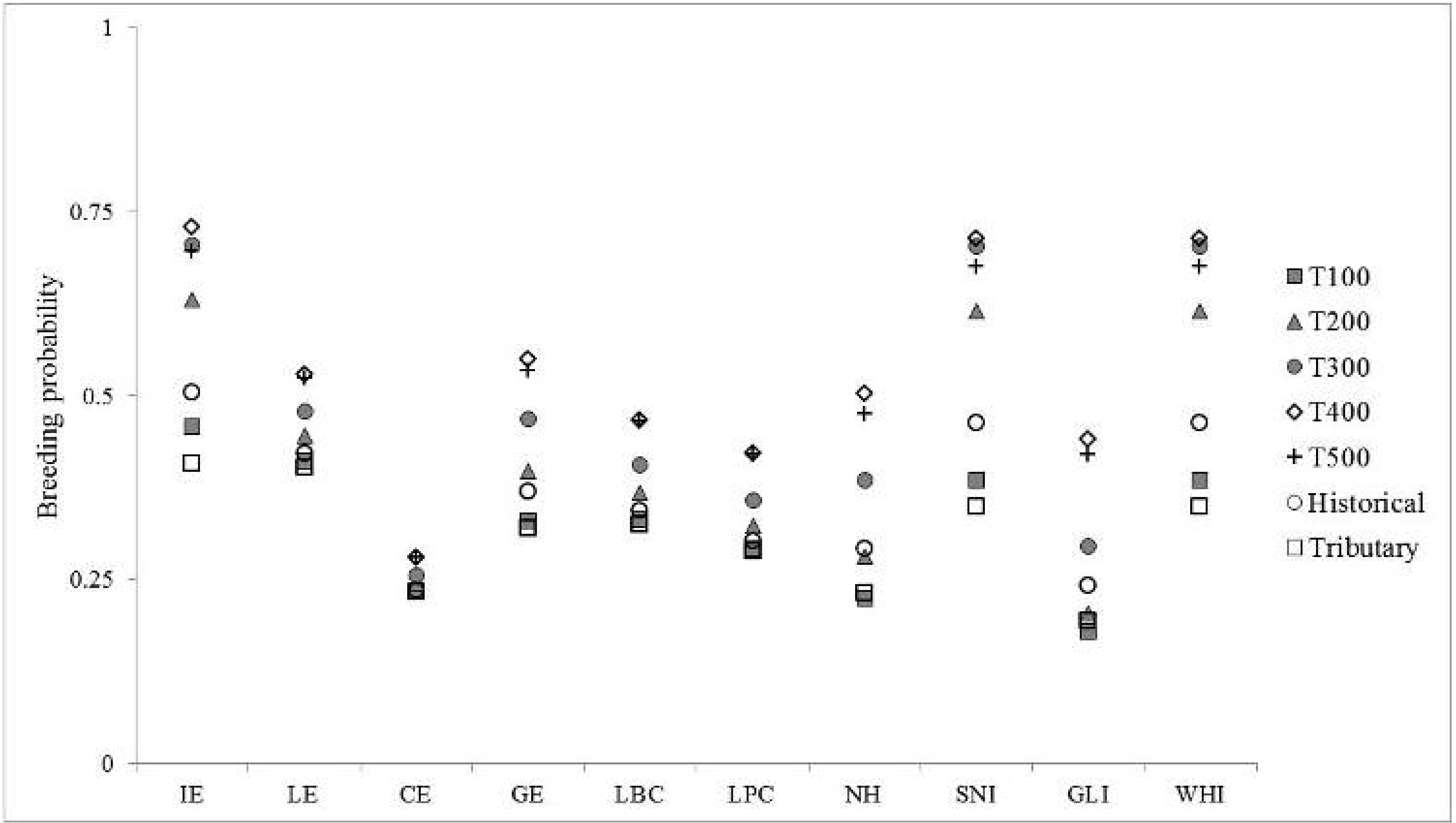
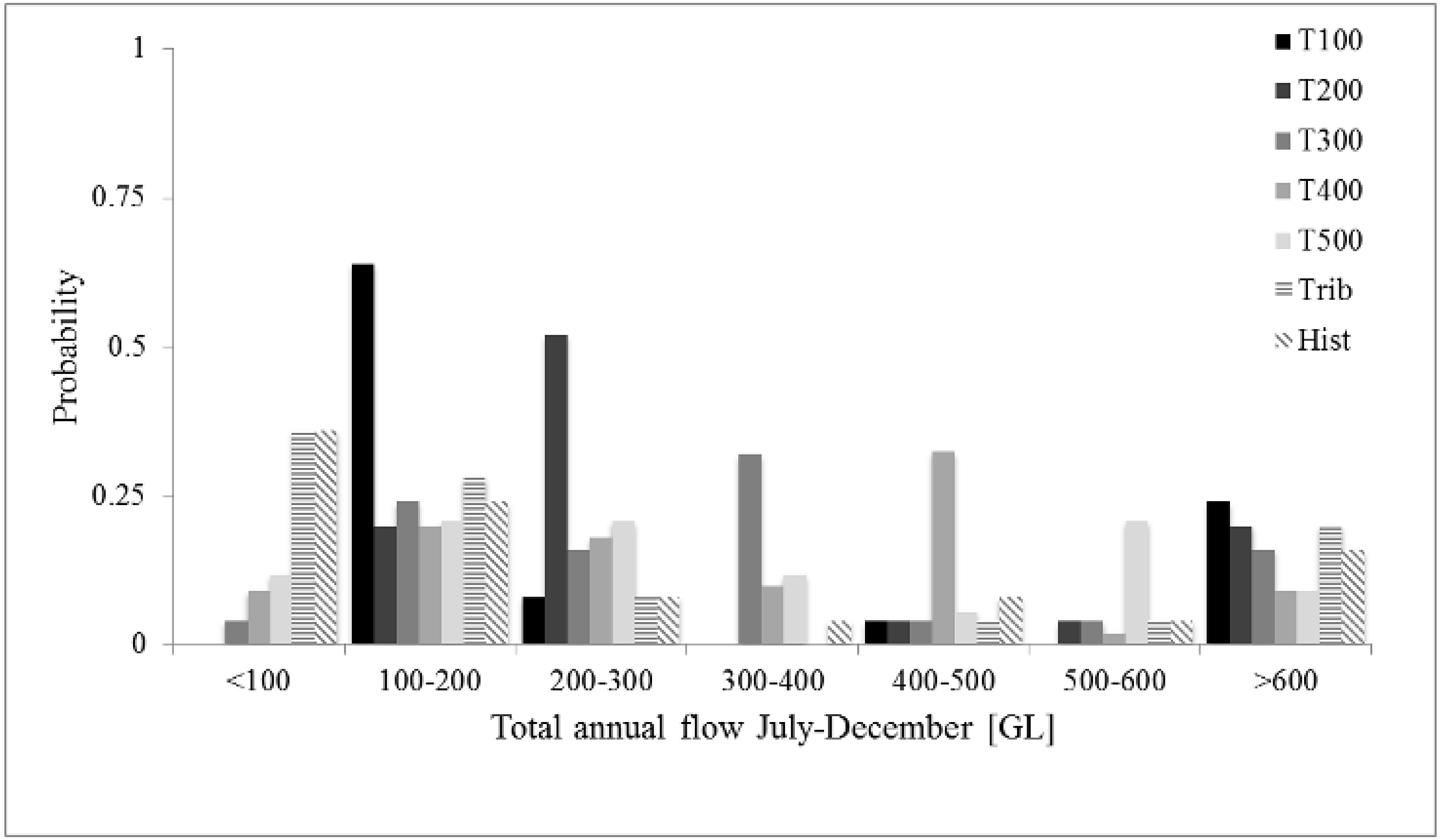


Figure 30 Frequency of flows under each management scenario



Discussion

Breeding of colonial waterbirds in the Macquarie Marshes was highly responsive to flows (Figure 26 and Table 19, (Kingsford and Johnson, 1998, Kingsford and Auld, 2005a, Arthur et al., 2012), similar to other colonial waterbirds (Stolen et al., 2005, Amat and Green, 2010). This pattern was consistent across species for the Macquarie Marshes, although thresholds differed (Table 20). This was probably related to the strong relationship between flow and inundated area (Ren et al., 2009, Thomas et al., 2011a), providing extended opportunities for colonial waterbirds to forage, build body condition, breed and provision chicks (Good, 2002, Kingsford and Norman, 2002, Harrison et al., 2010, Ma et al., 2010). Given that most of the flow is regulated by large upstream dams and there is a reasonably high quantity of this flow (~300,000ML) dedicated to the environment, there is considerable opportunity to manage environmental flows to improve the likelihood of breeding by colonial waterbirds, particularly in the ecologically degraded Macquarie Marshes (OEH, 2012c).

The Macquarie Marshes Adaptive Environmental Management Plan (AEMP) aimed to guide restoration of critical ecological functions and habitats in the Macquarie Marshes(DECCW, 2010b), followed by a growing emphasis on developing a framework for Strategic Adaptive Management (SAM) for the management of the Macquarie Marshes (Kingsford et al. 2011a). As part of this process, there is a need to develop a more flexible updateable tool for prioritisation of management actions for key assets and functions in the Macquarie Marshes, including the management of environmental flows (DECCW, 2010b, Kingsford et al., 2011a, Kingsford and Biggs, 2012a). Prioritisation and delivery of environmental water is a key component, inevitably requiring iterative annual planning process, given climatic circumstances, storage capacity, and environmental condition of the ecological assets at any point. Goals for colonially breeding waterbirds aim to establish small breeding events (<20,000) every two to three years and large breeding events (>20,000) every ten years (DECCW, 2010b). Our modelling indicated that probabilities of achieving such goals were maximised when environmental flows were diverted to the northern and southern section of the Macquarie Marshes (Figure 24 & Figure 28, Table 20). Small flows could trigger breeding events in the northern and southern section, but large flows were needed to stimulate breeding of colonial waterbirds in the eastern section. Despite this, many other ecological communities and processes in the eastern section benefit from small flows.

Managing water for successful breeding of colonial waterbirds in the Macquarie Marshes is central to the management of the entire ecosystem for three key reasons. First, the Macquarie Marshes are the most important wetland in Australia for breeding of colonial waterbirds, in terms of colony sizes, number of breeding species, and frequency of breeding (Kingsford and Thomas, 1995, Kingsford and Auld, 2005a). The waterbird communities and abundances are key criteria in the Macquarie Marshes' recognition under The Convention on Wetlands of International Importance (Ramsar Convention, 1971, OEH, 2009). Second, colonial waterbirds are particularly useful as indicators of wetland ecological health (Stolen et al., 2005). Biotic surrogates of ecosystem response are important given limited resources, providing an assessment of the responses and condition of ecosystems (Cairns et al., 1993, Hilty and Merenlender, 2000). The value of breeding of colonial waterbirds as an index originates from three attributes: ease of detection and measurement, sensitivity to environmental change, and value to the public as an iconic species. Waterbirds are useful as indicators because they are abundant, conspicuous, and importantly are a vital component of the wetland (Paillisson et al., 2002, Kingsford and Auld, 2005a, Stolen et al., 2005). They are also at the top of the food web, potentially reflecting the entire trophic structure (Fox and Weseloh, 1987, Kingsford and Porter, 1994, Shear et al., 2005). Finally, their colonial habit makes them relatively easy to monitor resulting in long-term continuous data for waterbird breeding within the Macquarie Marshes, since 1986, allowing development of robust ecological response models for water management decision-making (Kingsford and Johnson, 1998, Kingsford and Auld, 2005a).

More specifically, their non-linear (i.e., threshold) response to availability of water and extent of flooding provides critical information for potential transitions between different ecosystem states (Eiswerth and Haney, 2001). This is especially important for adaptive management aiming to identify solutions through constant re-evaluation of the ecosystem response to management (Walters, 1986, Gunderson, 1999). Threshold responses can be measured and quantified, identifying potential transitions between ecosystems states. Understanding minimum thresholds transitioning from desired to undesired states can help manage the system for resilience (Groffman et al., 2006). Defining desirable ecosystem states and limits, based on input of all stakeholders, can guide decision-making and encourage pre-emptive policy and legislation (Kingsford et al., 2011a). Importantly, our ability to identify quantitative relationships between flow volumes and ecological responses can support developing robust regional environmental flow guidelines (Poff et al., 2010). These issues are critical for environmental flow management broadly and its effectiveness for the management of the Macquarie Marshes. Australia is obligated to maintain the wetland's ecological character. Over decades, dams allowing water abstractions have caused degraded the Macquarie Marshes, including its abundant waterbird populations (Kingsford and Thomas, 1995, Kingsford and Johnson, 1998). This led the Australian Government to inform the Ramsar Bureau under Article 3.2 of significant reduction in health, diversity, of key wetland vegetation communities and the likelihood of a change of ecological character in key ecological assets (DEWHA, 2009, DEWHA, 2010). Such impacts and their management challenges represent a global problem for freshwater ecosystems, including protected areas, where authorities have consistently failed to meet conservation objectives largely due to impacts of water-resource development (Gibbs, 2000, Levin et al., 2009, Zhang et al., 2010, Hermoso and Clavero, 2011, Kingsford et al., 2011b, Pittock and Hartmann, 2011). Three interrelated factors drive environmental flow management, policy, and legislation: concern about significant ecological changes; a restoration imperative to address this problem followed by accountability for substantial public investment in the buying of environmental water.

We showed that effectiveness of alternative environmental flow management strategies using different volumes could be assessed using a Bayesian Belief Network (BBN), based on modelled breeding probabilities and identified thresholds. This provided an intuitive decision-making framework for conservation management where a key goal is the long-term sustainability of waterbird breeding (Figure 26). The BBN depicted the likelihood of colonial waterbirds breeding to specified total annual spring flows (July-December) for each of the two Macquarie Marshes areas (Figure 24). This allowed us to compare the long-term effects of alternative management options on different spatial aspects of colonial waterbird breeding, within a spatial framework. This is important because environmental flow managers have some control of the direction of environmental flows to the east (northern and southern section) or the eastern section (Figure 24). This BBN was effective in differentiating different strategies for environmental flows and their effect on the probabilities of breeding of different colonial waterbird species (Figure 29). Targeting larger minimum annual flow targets to the Macquarie Marshes significantly improved outcomes over the regulated historic flow regime (1986-2010) management, increasing the frequency of waterbird breeding colonies in the Macquarie Marshes by nearly 50%. More sophistication was provided by designing the BBN for each management zone and different species, testing effects of different environmental flow management strategies. This clearly allows conservation managers to test options for release of environmental flows over time. A strategy based on release of small environmental flow allocations could support breeding of IE, WHI, and SNI but large flooding events would be needed to trigger LPC, NH and CE breeding (Figure 27, Table 20). Such information would allow targets for breeding to be set for different species, ensuring that the diversity of colonially breeding species is maintained. Importantly, this BBN can be easily integrated into an adaptive management framework (Kingsford et al., 2011a, Kingsford and Biggs, 2012a). In particular, new information can be easily incorporated, updating the models for improved predictions for management. One of the critical aspects of adaptive management is the ability to test different strategies of management, carry out the management, and then report on its effectiveness (Holling, 1978). BBNs lend themselves well to this framework with feedback loops that continually update the relationships that underpin the modelling allowing strategy modelling across different spatial and temporal scales and different species. Ultimately, it is critical that monitoring programs, modelling, and updating have tangible feedback loops directly related to management outcomes.

Our models simply provide a useful tool for managers; they are not a panacea for management decision-making. Other factors are clearly important for such an ecologically complex system. For example, Terrigal 1 on the eastern side is the most important sites in the Macquarie Marshes for diversity of colonially breeding waterbirds (Table 19) and yet it required large flows to trigger breeding. It was also the only site which had the rare distinction of supporting breeding Pied Herons (Kingsford and Auld, 2003). It is also a privately owned part of the Ramsar site (OEH, 2009). It is critical that such site regularly supports colonial waterbird breeding, representing its recorded diversity. Simple isolation and management of these colony sites will also not achieve conservation (Kingsford, 2001, Kingsford and Thomas, 2004). Breeding waterbirds depend on the large extent of flooding (Stolen et al., 2005, Timmermans et al., 2008) and access to abundant food resources although little is known of factors determining such dependencies. Related to this, duration, timing are also critical for ensuring long-term breeding success of colonial waterbirds (Kingsford and Auld, 2005a). Other goals exist for the management of the Macquarie Marshes, including maintenance and restoration of vegetation communities, other avifauna aquatic & semi-aquatic herpetofauna, and native fish species (DECCW, 2010b). These are not divorced from the breeding of colonial waterbirds. Vegetation communities support significant wetland species diversity including colonial nesting waterbirds, migratory shorebirds, frogs, fish, and reptiles (Healey et al., 1997, Mussared, 1997, Shelly, 2005a). Vegetation type and condition are critical for nesting habitat of colonial waterbirds, particularly river red gum forests, reed beds and lignum in the Macquarie Marshes (Table 19), (Kingsford and Auld, 2003), and providing food essential for breeding success (Marchant and Higgins, 1990). The structure and condition of floodplain vegetation usually reflects a type flow regime and not surprisingly these are the areas which are traditionally used for colonially breeding waterbirds (Figure 24). A key goal should be maintenance of the vegetation growth, condition and recruitment in these sites, requiring sufficient flows to inundate river red gums, reedbeds and lignum every few years (Roberts & Marston (2011). Given these dependencies, it is likely that disparate goals for organisms align but this needs to be tested. This requires assessment of competing assets and alternative models within the Macquarie Marshes to optimise management of the Macquarie Marshes for resilience (Walters and Hilborn, 1978, Linkov et al., 2006).

Management of complex ecosystems depends on good understanding of the responses of organisms to the main drivers of change. Breeding of colonial waterbirds is strongly associated with flows, providing opportunity for testing management decisions for environmental flows. We showed how a BBN built on relationships between flow and breeding of colonially breeding waterbirds provided a means for testing different management strategies for release of environmental flows. Importantly, such a modelling framework can be improved within an adaptive management framework, with new data potentially reducing uncertainties. There is considerable opportunity for such a framework to be adopted for other ecosystem attributes, following understanding of their responses to the flow regime. The breeding of colonial waterbirds provides an excellent indicator, given the strength of the relationship with flow regimes, for continuing to test effectiveness in the management of environmental flow in the Macquarie Marshes and significance for policy and management (e.g. Ramsar criteria) but more generally, such methods could be applied to other major wetlands where colonial waterbird breeding is a key response for management.

3.3.3. State-transition analysis of flood dependent vegetation communities

Introduction

Wetlands are characterised by a unique ecology displaying cyclic patterns of succession (Peet 1992), dominantly driven by extreme variability in hydrological patterns across the landscape. While exposure to wet conditions can drive a succession process towards an aquatic condition, exposure to drying conditions can transform a community to a terrestrial one. These unique conditions promote bidirectional succession of wetland communities, promoting multiple stable states (Beisner et al. 2003). The eventuality of stable state (e.g., vegetation community) is determined by the magnitude and duration of perturbation (e.g., drying or wetting) to the state variables (e.g., specific hydrological regime). Once a stable state reached, the community will persist until exposed to a large enough perturbation. Transitions between stable states are commonly triggered by multiple disturbances and may occur rapidly or over prolong periods (Westoby et al. 1989; Stringham et al. 2003). Ecological models linking successional ecological theory and ecosystem management are developing as tools for describing and predicting community change (ref). Such models have the ability to promote understanding and enhance predictive capabilities of vegetation change as a response to climatic and managerial variations.

State-and-transition models (STMs or S&T models) were developed as flexible conceptual frameworks of vegetation change used for management and research (Westoby et al. 1989). Originally developed as a tool for describing vegetation change in rangeland ecosystems, it has since been widely adopted (Zweig and Kitchens, 2009). STMs can be used for communicating understanding of ecosystem, dynamics among scientists, managers, and policy makers (Ludwig et al., 1996) as well as identifying alternative management opportunities (Czembor and Vesk, 2009). More recently, STMs have been criticised for lacking predictive capacity, representation of uncertainty, and ability to update (Bashari et al., 2008, Rumpff et al., 2011). These shortcomings have restricted the use of STMs as a decision tool on which to prioritise management strategies. Quantitative modelling of state transitions can significantly bolster STM capacity in supporting practical decision-making as well as our understanding of

The Macquarie Marshes (MM) are an extensive, diverse and dynamic wetland system that covers an area of approximately 200,000 ha (DLWC 1996, Button 2004), while the MM Nature Reserve (MMNR) is approximately 20,000 ha (NPWS 2012). The MMNR was listed as a Ramsar site in 1986 (ref). The MM are complex mosaic of swamps, lagoons, channels and gilgaied floodplain inundated by flooding from the lower Macquarie River and its distributary streams. The MM incorporate extensive areas of wetland vegetation, requiring regular, frequent, and prolonged flooding. Prominent vegetation types include: reed swamp (*Phragmites australis*), river red gum (*Eucalyptus camaldulensis*), Black Box (*Eucalyptus largiflorens*) Coolibah (*Eucalyptus coolabah*), Lignum (*Muehlenbeckia florulenta*), and water couch grasslands (*Aspalum distichum*) which provide important habitat for many species of flora and fauna (Kingsford and Smith, 2010).

Degradation of the natural flow regime has led to decline in both extent and condition of wetland vegetation across the Macquarie Marshes (Paijmans 1981; Brander 1987; Goodrick et al 1991; Bowen & Simpson 2010), with recent colonisation of salt tolerant xenomorphic shrubs. The MM are managed for many ecological assets influenced by drought conditions and water resource development (Kingsford and Thomas 1995; Kingsford and Thomas 1998; Thomas et al. 2011; Ren et al. 2010; Ren and Kingsford 2011; Steinfeld and Kingsford 2012). In recent years, increased environmental flow allocations by the New South Wales and Australian Governments have necessitated the formalisation of strategic planning of environmental water allocation. Decisions on how best to allocate water across the MM to protect these ecological assets in the long-term are needed.

Here we employ a quantitative approach to model the State and Transition probabilities of vegetation communities found within the MMNR. We use two vegetation surveys taken 16 years apart to model these changes. Using our novel approach, we extend our results and provide predictive transition probabilities for the vegetation communities based on two contrasting hydrologic regimes (regulated and unregulated). The capacities we build here provide a significant advance in STMs and conservation management.

Vegetation and Inundation

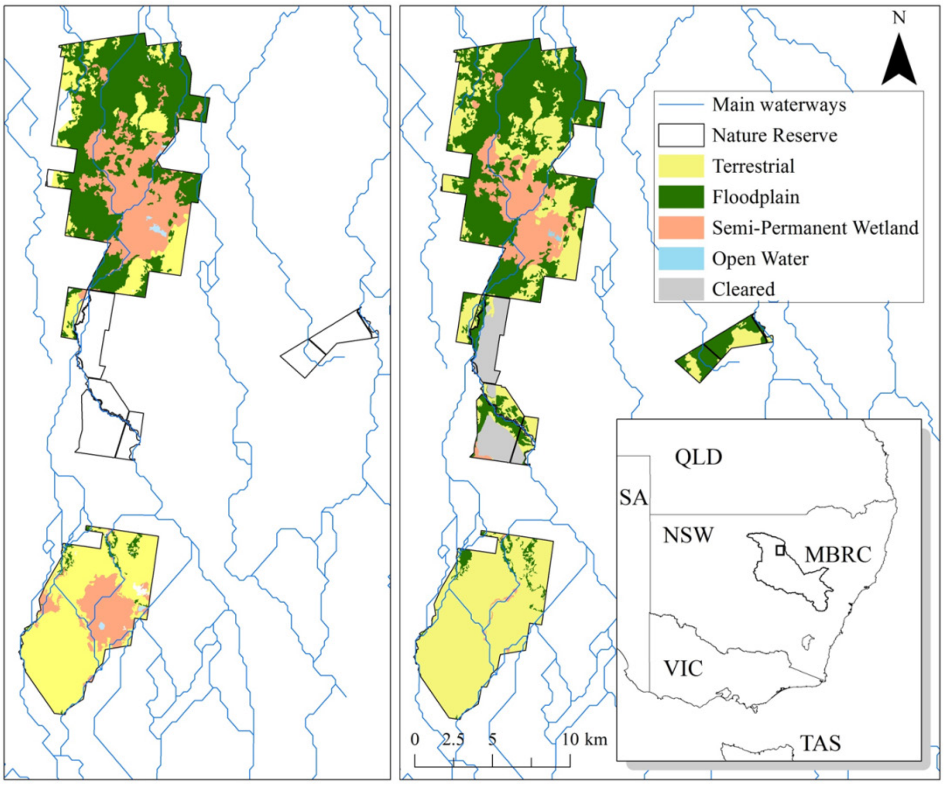
We examined changes in vegetation communities occurring in the Macquarie Marshes Nature Reserve (Figure 31), 1991-2008, based on respective maps of dominant species and structural characteristics (Wilson, 1992, Bowen and Simpson, 2008). The 1991 vegetation map was based on aerial black and white photo interpretation to delineate vegetation surveys followed by ground surveys (Wilson, 1992). The types were determined by their dominant species and their structural characteristics such as canopy cover, density, and height. In 2008, delineation of vegetation communities was updated using a digital colour aerial photography (Bowen and Simpson, 2008). Floodplain wetlands in the semi-arid regions are particularly vulnerable to alterations in specific flow regimes (e.g., reduced variability and a lack of water) which can compromise their ecological integrity. Floodplain vegetation communities affected by reduced river flows transition towards communities that are more terrestrial with flood dependent communities moving into more aquatic habitats (Bren 1992). To express this process, we grouped mapped species into four broad vegetation communities along an increasing requirement gradient of flood frequencies: (i) Terrestrial, (ii) Semi-permanent wetland, (iii) Floodplain vegetation, and (iv) Open-water (Table 21). We then divided the Macquarie Marshes Nature Reserve into 100x100m cells, within which the dominant vegetation community was classified (n=18,266 cells, ~182km^2).

To measure the extent and frequency of flooding that might drive transition between vegetation communities, we relied on annual inundation mapping previously derived from near-spring digital Landsat images (Multispectral Scanner (MSS) and Thematic Mapper (TM) imagery) between 1979 and 2007 (Thomas et al., 2011a). Thomas *et al.* (2011) classified each cell (25mx25m) as inundated by integrating water and vegetation response using Iterative Self-Organizing Data Analysis (ISODATA) clustering. From these inundation maps, we calculated for each cell the probability of inundation at varying time spans: 1979-2007, 1991-2007, and 2003- 2007. We also calculated for each cell the time since last inundated (cell not inundated prior 1979 were given a value of 30) and distance to nearest stream.

Table 21 Grouping of mapped species into four broad vegetation communities along an increasing requirement gradient of flood frequencies: (i) Terrestrial, (ii) Semi-permanent wetland, (iii) Floodplain vegetation, and (iv) Open-water.

Species	Vegetation Community
Black Box	Dryland
chenopod shrubland/grassland	Dryland
Cultivation	Dryland
Dead Trees	Dryland
Grassland/Cleared land	Dryland
Myall	Dryland
Coolabah	Floodplain vegetation
Lignum	Floodplain vegetation
Poplar Box	Floodplain vegetation
River Cooba	Floodplain vegetation
River Red Gum	Floodplain vegetation
Common Reeds	Semi-permanent wetland
Cumbungi	Semi-permanent wetland
Mixed marsh	Semi-permanent wetland
Water Couch	Semi-permanent wetland
Open water	Open water

Figure 31: Extent of vegetation communities in 1991 (left) and 2008 (Right) within the Macquarie Marshes Nature Reserve



Modelling transition probabilities

We investigated which of five environmental factors most influenced the state transition probabilities. Probability of inundation were strongly correlated among each other ($r>0.75$) and so were not included together in any given model. Some correlation was apparent between time since last inundated and probability of inundation ($r= -0.75$,-0.69, -0.51). Distance to nearest stream was not significantly correlated with any of the other variables ($r<0.15$). We used a Bayesian logistic regression approach to model the probability of a transition between different vegetation communities or states at each cell. We implemented the Bayesian approach which probabilistically incorporates underlying parameter uncertainties within the inferential framework, providing a natural framework for prediction, uncertainty assessment, and decision making (e.g. Gelman et al. 2003).

We defined i(j) (initial) and f(j) (final) as the vegetation state at location j (1-18,266) at one of survey times ($Year_{1991}$ and $Year_{2008}$). The probability of transitioning from an initial state I to final state F by p[i,f], for i, f=1, …, 5. For each state I, the sum of transition probabilities equalled one (sum_f p[i,f]=1). For each cell j, we had

f(j) ~ Multinomial(1, p[i(j)])

so that f(j) was modelled as a single draw from a Multinomial distribution with probability vector p[i(j)]=(p[i(j),1], …, p[i(j),5]). To build a dependence on environmental factors into the transition probabilities, we modelled them using logistic regression:

$$Log \frac{\mathrm{p[i,f]}}{(1-\mathrm{p[i,f]})} = beta_s * X_1,$$

where X was a matrix of location-specific predictors (explanatory variables), and $beta_S$ were a vector of parameters to be estimated for transitions from state I. We used vague normal priors for each element of $beta_S$, subject to the condition of \sum_f p[i,f]=1 for each state I. We used OpenBUGS (Spiegelhalter et al., 2003), with our inference based on 10,000 samples from the posterior distribution of each model following 1,000 iterations burnin.

We selected among models with different predictors, based on the Deviance Information Criterion (DIC; Spiegelhalter et al. (2003)). DIC values reflected a trade-off between the fit of a model and its complexity, with small values indicating a better model. DIC values can be interpreted in a similar way to AIC values (Burnham and Anderson, 2002, Spiegelhalter et al., 2002). When comparing models, a difference of less than two between their DIC values indicated that they were largely indistinguishable.

Predictive capacity

To demonstrate a predictive capacity and examine the consequences of dissimilar hydrological regimes, we compared the persistence probability (the probability of non-transition) of semi-permanent wetland communities in the Macquarie Marshes Nature Reserve under an unregulated and regulated systems. We used the integrated flow and flood modelling (IFFM) method to simulate annual flows and spatial flooding in the Macquarie River (Ren and Kingsford, 2011). The statistical method relies primarily on the statistical relationships among data for annual flow, rainfall, and inundation patterns to predict inundation extents (Ren et al., 2010). It has allowed generation of inundation maps without river regulation and diversions, based on modelling of flows before the Macquarie River was regulated by large dams and flows were diverted. We used the unregulated and regulated inundation maps (1991 to 2008) from the integrated flow and flood modelling to predict transition probabilities and compare spatial variation.

Results

There were significant transitions of vegetation communities in the Macquarie Marshes Nature Reserve between 1991 and 2008 vegetation surveys (χ^2=693.43, df=3, p<0.0001). Overall, vegetation communities became increasingly drier (Table 22). Terrestrial extent increased by 38%, largely at the expense of Semi-permanent wetland and open-water extent, which decreased by 21% and 73%, respectively. The extent of floodplain vegetation remained largely unchanged (Table 22). Concurrently, there was a consistent decrease in inundation probability. A 10-year moving average starting at 1988 (i.e., 1979-1988) decreased from 0.48±0.5SD, through 0.40±0.49SD in 2000 (i.e., 1991-2000), to 0.3±0.46SD in 2007 (i.e., 1998-2007). Specifically to examined inundation matrices; 1979-2007, 1991-2009, and 2003-2007, average inundation probability was 0.4±0.31SD, 0.32±0.3SD, and 0.15±0.24SD, respectively.

The null model for transition probabilities supported observed changes in the vegetation communities between 1991 and 2008 and inundation history (Table 22). Terrestrial communities had the highest probability of persisting (p_p=0.978±0.002SD) and the lowest probability of inundation (p=0.082±0.132SD). Floodplain vegetation communities remained very stable, with persistence probability of p=0.971±0.002SD and ample likelihood of inundation (p=0.437±0.289), (Table 22). Floodplain vegetation communities that experienced higher probability of inundation (p=0.767±0.128) transitioned to Semi-permanent wetland communities (p=0.016±0.002). Semi-permanent wetland communities had a lower probability of persistence and a significant likelihood of transitioning to terrestrial communities (Table 22). Explicitly, cells that experienced lower inundation probabilities (p=0.252±0.179SD) were more likely to transition to terrestrial communities (p=0.505±0.007), while cells with higher inundation probabilities (p=0.676±0.166SD) were more likely to persist (p=0.455±0.007).

Table 22: Extent of vegetation communities' [km2], their transition probabilities (±SD), along with inundation probabilities (±SD) (in parentheses), between 1991 (rows) and 2008 (columns).

		2008 Terrestrial (90.2 km^2)	Floodplain vegetation (68.7km^2)	Semi-permanent wetland (22.8km^2)	Open-water (0.2km^2)
1991	Terrestrial (65.7km^2)	0.978±0.002 (0.082±0.132)	0.018±0.002 (0.152±0.169)	0.004±0.001 (0.389±0.159)	0±0 (-)
	Floodplain vegetation (67.9km^2)	0.014±0.001 (0.22±0.191)	0.971±0.002 (0.437±0.289)	0.016±0.002 (0.767±0.128)	0±0 (-)
	Semi-permanent wetland (47.5km^2)	0.505±0.007 (0.252±0.179)	0.039±0.003 (0.508±0.236)	0.455±0.007 (0.676±0.166)	0±0 (-)
	Open-water (0.8km^2)	0.462±0.053 (0.224±0.159)	0.012±0.012 (-)	0.263±0.048 (0.765±0.083)	0.263±0.047 (0.734±0.096)

Model selection identified probability for inundation between the two vegetation surveys (1991 and 2007) as the best single predictor in explaining state transition probabilities (DIC=7852; Table 232). When paired with distance to nearest stream, a best model was identified (Table 23). As suspected, distance to stream acted as a buffer against low inundation probability, whereby transition to drier vegetation communities was less likely. The mean and SD of the distribution of the regression coefficients are presented for the best models (Table 24).

Table 23: Analysis of importance of factors affecting predictive performance, from the Bayesian logistic regression model for predicting the probabilities of transition between vegetation communities.

Model	DIC[1]
prob1991_2007 + Distance to River	7756
prob1991_2007 + Time since last Flood	7834
prob1991_2007	7852
prob2003_2007	8294
p1979_2007	8344
Time since last Flood	9091
Distance to River	11490
Null	11630

Table 24: Bayesian logistic regression coefficients and SD (a±SD/b±SD/c±SD)) for predicting the of the logit model for transition probabilities of transition from one vegetation community to another as a function of 16-year inundation frequency and distance to nearest stream

$(logit(p) = a + b * p\_inun1991\_2007 \ + c * distance\ to\ stream)$

	Coefficients	Dry-land	Semi-permanent wetland	Floodplain	Open-water
Terrestrial	a	4.875±1.782/	-6.226±0.3714/	-3.874±0.1807	-9.651±1.42/
	b	1.758±1.639/	5.242±1.372/	/2.424±0.6382/	0.4811±1.603/
	c	-4.985±1.914	-0.02666±4.51	-0.1371±4.513	0.01893±4.414
Semi-permanent wetland	a	4.197±1.307/	-3.39±0.6603/	-2.948±0.5368/	-6.496±1.035/
	b	-9.13±1.519/	5.946±0.7247/	0.09729±0.3747/	-3.523±1.817/
	c	-12.06±4.948	-0.09459±4.423	-0.02021±4.55	-0.007128±4.348
Floodplain	a	-2.814±0.2419/	-6.753±0.5653/	6.852±1.265/	-9.209±1.55/
	b	-3.548±0.5553/	4.757±0.8665/	3.634±2.765/	-3.876±4.157/
	c	-4.374±1.491	-0.08699±4.346	0.06962±4.555	0.005638±4.559
Open Water	a	2.315±1.613/	-1.132±3.008/	-3.521±1.4/	-0.8852±2.89/
	b	-3.286±3.457/	2.318±1.697/	-2.523±1.826/	1.171±2.704/
	c	-1.634±2.823	0.1031±4.499	-0.2077±4.46	0.04917±4.419

Using the best model (Table 23 & Table 24), we predicted persistence probability (p_p) for each of the four vegetation communities as a function of a 16-year probability of inundation (p_i) while keeping distance to nearest stream constant at the average value of 900m (Figure 32). Credible intervals of modelled transition probabilities increased as distance to nearest stream increased. Persistence probability of terrestrial communities diminished as the probability of inundation increased but they still remained reasonably (p_p=0.68, Figure 32). Conversely, persistence probabilities for open water communities increased with inundation, from p_p=0.2 to p_p=0.36. Floodplain vegetation communities displayed a subtle hump shape response to inundation probability, starting at p_p=0.96, reaching maxima of p_p=0.98 around p_i=0.4 and then decreasing to p_p=0.89 (Figure 32). Decreased persistence as probability of inundation increases can be attributed to increased transition probability to Semi-permanent wetland communities. Semi-permanent wetland communities presented the strongest sensitivity to changes in inundation probabilities increasing from p_p=0.03 to p_p=0.94 with increased inundation. The sharpest change (threshold) in probability was observed at p_i≈0.44 with an observed rate of change of 2.39.

Given the current regulated system, semi-permanent wetland communities had an average persistence probability of p_p=0.33±0.35SD. This significantly differed to their average persistence probability of p_p=0.60±0.37SD under an unregulated flow regime. Spatially, the most significant changes in transition probabilities occurred in the southern parts of the Macquarie Marshes nature reserve.

Figure 32: Probability of persistence of vegetation communities as a function of 16-year probability of inundation (at a constant distance of 1m to nearest stream).

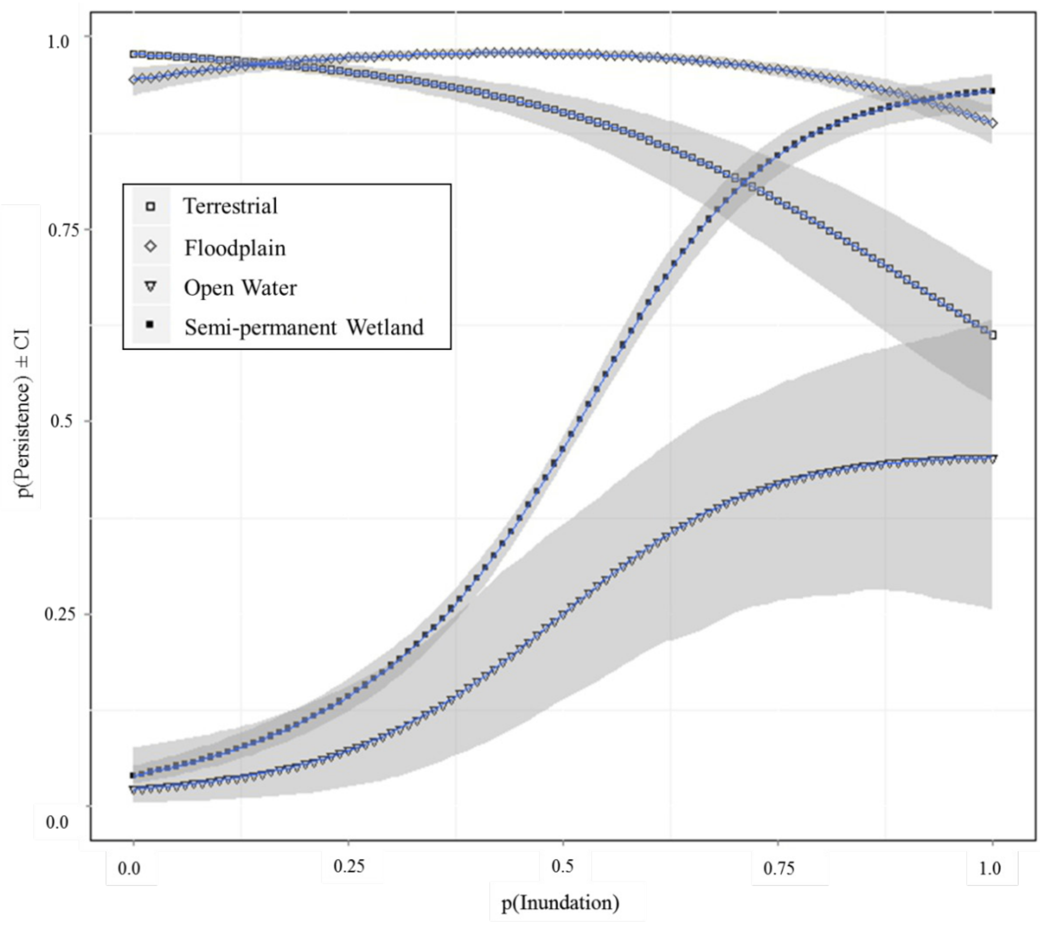
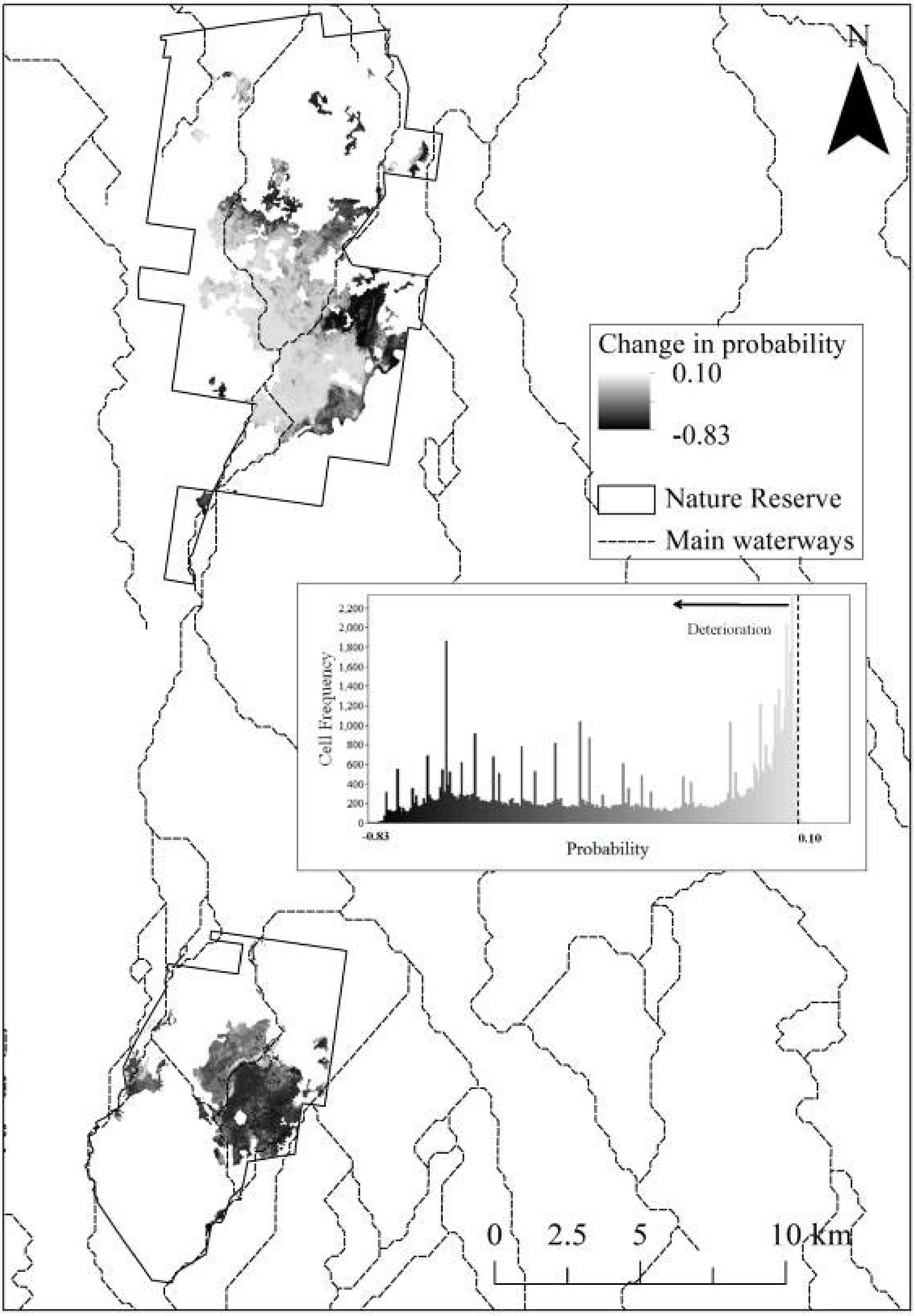


Figure 33: Change in persistence probability of semi-permanent vegetation communities when shifting from an unregulated to a regulated system.



Discussion

Flooding frequency over the last two decades (1991-2008) has been the primary driver of change in vegetation community composition within the Macquarie Marshes (Table 23). Significant extent transitions have occurred between vegetation communities, with communities transitioning towards more dry states (Table 22). While Terrestrial extent increased by 38%, semi-permanent wetland and open-water decreased by 21% and 73%, respectively. We find that these changes are significantly driven by reduction in inundation frequencies (Table 22 and Table 23). Albeit, we find that distance to stream can act as a buffer against low inundation probability. Water flow is known to be a key driver shaping the physical habitat in streams and floodplains, subsequently determining the biotic composition of the ecosystem (Bunn and Arthington, 2002, Carlisle et al., 2010). Floodplain vegetation communities are especially reliant on unique flow regimes, characterised by high variability of flows and flooding patterns often referred as ‘boom and bust’ cycles (Kingsford, 2000, Frazier and Page, 2006, Young and Kingsford, 2006, Thomas et al., 2010a). In the Macquarie Marshes, intensive river regulation since the 1960’s significantly transformed the natural flow regime of the system, critically reducing the extent, duration, and frequency of flooding across the floodplain (CSIRO, 2008c). Consequent changes in flow and inundation regimes have had severe repercussions for the many ecological assets of the Macquarie Marshes including waterbirds (Kingsford and Thomas, 1995, Kingsford and Johnson, 1998, Kingsford and Auld, 2005a), fish (Puckridge et al., 2000), invertebrates (Jenkins and Boulton, 2007), and vegetation (Brock et al., 2003, Thomas et al., 2010a).

Across the Macquarie Marshes, semi-permanent wetland vegetation communities (i.e., common reed, water couch, and mixed marsh) displayed the most significant transformation, with a 0.5 probability of transitioning to terrestrial vegetation communities, dominated by chenopod shrubland (Table 22). Observed transitions to drier vegetation communities are a clear indication of inadequate flooding regime (Thomas et al., 2010b). Semi-permanent wetland communities require highly frequent flooding at least once every two years for common reed and an annual flooding for water couch (Roberts & Marston 2000; Rogers 2011). Water couch grasslands, a key native plant of conservation concern, is especially prone to changes in inundation frequency. Water couch is a prolific seeder but successful seed germination is limited compared to regeneration from fragments or buried nodes (Middleton 1999). Extensive range loss due to drying can severely restrict its ability to recover after prolong droughts due to its dependence on adult plants. Importantly in the Macquarie Marshes, these communities support significant wetland species diversity including colonial nesting waterbirds, migratory shorebirds, frogs, fish, and reptiles (Healey et al., 1997, Mussared, 1997, Shelly, 2005a). Common reeds provide habitat for many waterbirds as nest substrate for large ibis (*Threskiornis sp.*) breeding colonies as well as for the endangered Australasian bittern (*Botaurus poiciloptilus*), (Kingsford and Auld, 2003). Australian painted snipe (*Rostratula australis*), a nationally threatened and migratory species, and magpie goose (*Anseranas semipalmata*) have been recorded feeding on water couch seeds which may underpin their breeding success (Marchant and Higgins, 1990). Declining condition of vegetation communities underpinning the wetland ecosystem runs the risk of driving both ecological and social systems beyond viable thresholds. Inability to recognise deteriorating conditions of ecosystems, notably beyond resilience tipping points, and adapt accordingly, will ultimately result in the failure in obtaining conservation objectives for the wetland.

Understanding how ecosystems change in response to disturbance and developing ecosystem models are critical components of restoration and management ecology. Models of ecosystem dynamics include gradual continuum, stochastic, or threshold response (Hobbs and Suding, 2008). Considerable empirical evidence suggest most ecosystem can alternate among stable and functioning states (Beisner et al., 2003). First suggested by Lewontin (1969), the model predicts a threshold dynamic where small external changes in environmental conditions can push an ecosystem beyond a tipping point leading to substantial change in its function and/or community composition (Groffman et al., 2006). In riverine systems, extrinsic factor such as hydrology and geomorphology strongly influence inherent ecological processes (Church, 2002, Parsons et al., 2009). Thresholds are generally unknown and shifts in states can occur with little or no warning (Scheffer et al., 2009). With relevance to restoration and management ecology, ecosystem shifts can be irreversible or require more than "simply" restoring pre-threshold conditions (Carpenter and Brock, 2006, Scheffer et al., 2009). Given the high-stakes involved with crossing ecosystem thresholds, information regarding warning signs and cross-over points are vital for conservation management. Here we find strong thresholds ($p \approx 0.5$) dynamics in semi-permanent vegetation communities driven by the probability of floodplain inundation (Figure 32). Similarly, open water communities demonstrated a threshold response to inundation probability, although even under high inundation probabilities, persistence was not likely. This was likely a result of low flow volumes and shorter periods of flooding which are beyond the limits of presently existing information for the area. These were contrasted by lack of threshold response of terrestrial and floodplain vegetation communities and the overall high probability of persistence (Figure 32). For the floodplain system studied here, understanding the minimum flow requirements under which thresholds are likely to be crossed from desired to undesired stable states can help manage the system for resilience and avoid the consequences of exceeding them, which can limit future management actions (Groffman et al., 2006).

The resilience of an ecosystem can be defined as the amount of disturbance it can sustain without collapsing or transitioning, into a different state characterised by a different set of functions, structures, and processes (Walker and Salt, 2006). Resilience thinking views social–ecological systems as complex adaptive systems (Levin, 1998, Folke et al., 2002, Folke, 2006). Managing for resilience enables socio-ecological systems to withstand and minimise the risks associated with the inherent uncertainties caused by natural variability (Folke, 2003), particularly for Australian riverine systems with high variability and low predictability. Growing demand for freshwater resources will increased the catastrophic ecosystem regime shifts (Gordon et al., 2008). Worldwide, many freshwater ecosystems are shifting into degraded states (Rockström et al., 2009). Strategic Adaptive Management (SAM) of freshwater ecosystems is founded on complexity, resilience, and incorporating social–technological–economic-ecological–political values (Kingsford et al., 2011a). Strategic adaptive management recognises the inherent uncertainties of dynamic and unpredictable ecosystems but tests these uncertainties, progressively improving management (Kingsford et al., 2011a). A key step for the management of floodplain ecosystems is to define desirable ecosystem states and limits that can be used to guide decision-making, promote resilience, and encourage pre-emptive policy and legislation. Acquisition of environmental water entitlements by the New South Wales and Australian Governments in the past two decades (presently: 146243ML general security and 3340ML supplementary) has necessitated the formalisation of strategic planning of environmental water allocation (OEH, 2012d, SEWPAC, 2012). Strategic Adaptive Management framework could provide a more flexible updateable tool for prioritisation of management actions for key assets and functions in the Macquarie Marshes, including the management of environmental flows.

Monitoring is a critical component of adaptive management, designed to provide feedback on managerial decisions. The complexities of ecosystems and uncertainties that follow require setting up monitoring plans to continuously assess and evaluate response of ecological indicators to the consequences of management actions. This requires identifying some explicit indicators which most effectively and efficiently provide the requisite information allowing measurement of progress toward an articulated desired state. Indicators should be sensitive to change and could be measured using a range of methods, forming operational goals that articulate natural spatial and temporal variability. Here we find that semi-permanent wetland communities are highly important indicators; sensitive to changes in inundation frequencies and displaying a strongest threshold response (Figure 32). The relative short life-cycles and dependence on flooding make them a more suitable indicator of response than the long-lived woody vegetation species, whose response to inundation changes may not be evident for decades (Bacon et al. 1993; Capon 2005; George et al. 2005). Monitoring programs only deigned to assess the 'state' of the system will lead to management that is highly reactive to inherent variability of the system and introduces the risk of management by observation and 'pseudo-fact' (Rogers and Biggs, 1999) . Contrastingly, active management involves active pursuit of knowledge through experimental management. Designing powerful experiments with key indicators testing management actions has several benefits such as: accelerating the rate of learning, allowing more reliable interpretation of occurring change, preparing management when faced with novel uncertainties, and preventing critical large-scale mistakes (Poff et al., 2003, Medema et al., 2008, Kingsford and Biggs, 2012a). There are some opportunities to test effect of different management options in the Macquarie Marshes releasing environmental flows into different areas. Improving fine-scale hydrological and inundation models taking into account spatial complexities and connectivity are vital (Figure 33). Improved understanding of ecosystem thresholds through monitoring and can aid managers in determining which changes within their dynamic system are worthy of concern and facilitate strategic management (Fairweather and Lester, 2010). Ultimately, understanding how different indicators respond to the spatial and temporal patterns of flooding is critical to ensuring all ecosystems components are appropriately managed.

3.3.4. Process model for the Macquarie Marshes

We aimed to integrate all available ecological datasets to form a cohesive process model that would represent the likelihood of ecological outcomes to flow volumes, the dominant driver of the wetland ecosystem. Additional to colonial waterbird (3.3.2) and vegetation communities (3.3.3) specifically developed for this project, we utilised datasets collated and analysed independently for fogs, river red gums, and invertebrates.

River red gums

River red gum health estimates relied on work carried out by Peter Bacon (1993, 2004) and Katharine Catelotti (2012) (Bacon, 2004, Catelotti, 2012). The study examined the health of river red gum (*Eucalyptus camaldulensis*) at 22 sites within the Macquarie Marshes in 1993-1995, and 2004 (Figure 34). River red gum was a key floodplain species that can survive several years between flooding. Decline and death of this species is indicative of a major change in floodplain hydrology. Epicormic growth (0-3) was used as an indicator of recovery from periods of severe stress. Average score of epicormic growth was calculated for each of the four available years. We used the ratio between the 10-year probability of inundation and distance to nearest stream:

$$\frac{10 - \text{year inundation probability}}{\text{Log(distance to nearest stream)}}$$

as an explanatory variable of the logit relationship of epicormic growth (Figure 35) and crown density (Figure 36).

Figure 34: Long-term river red gum survey sites across the Macquarie Marshes

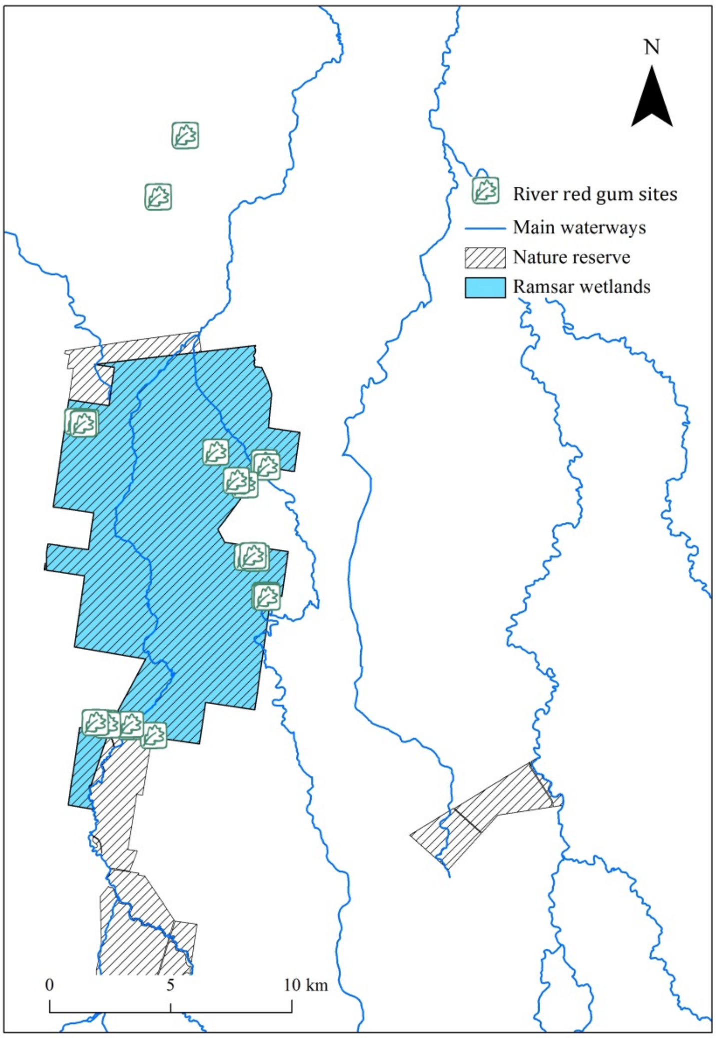


Figure 35: Modelled relationship between epicormic growth and inundation probability and distance to nearest stream

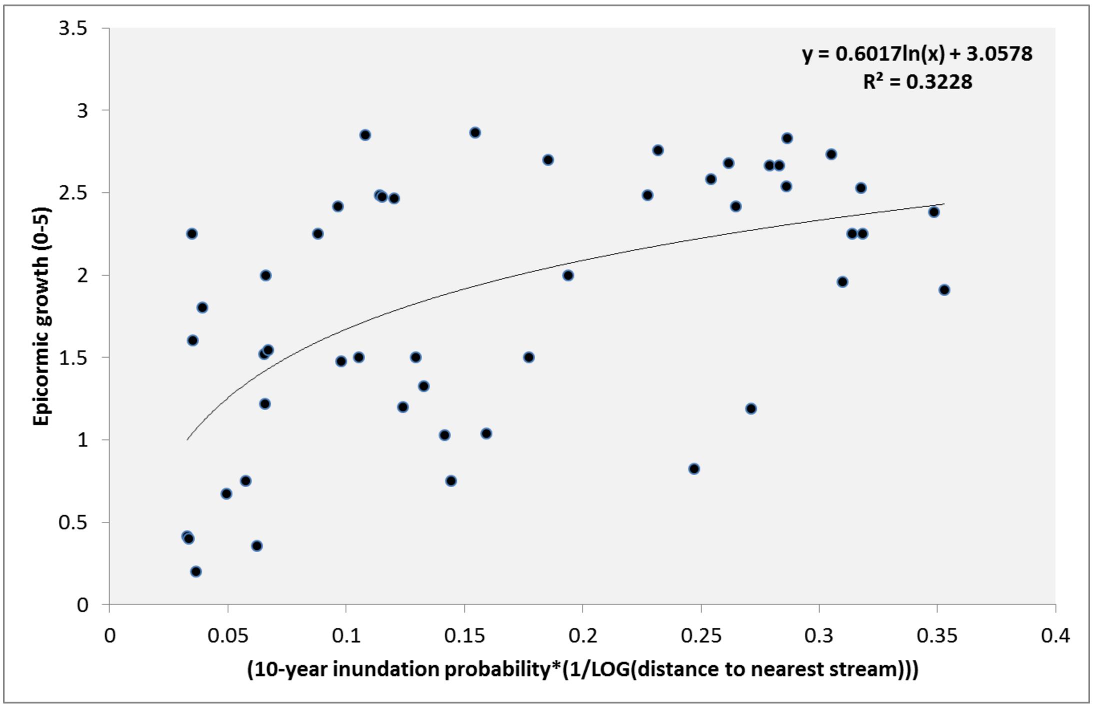
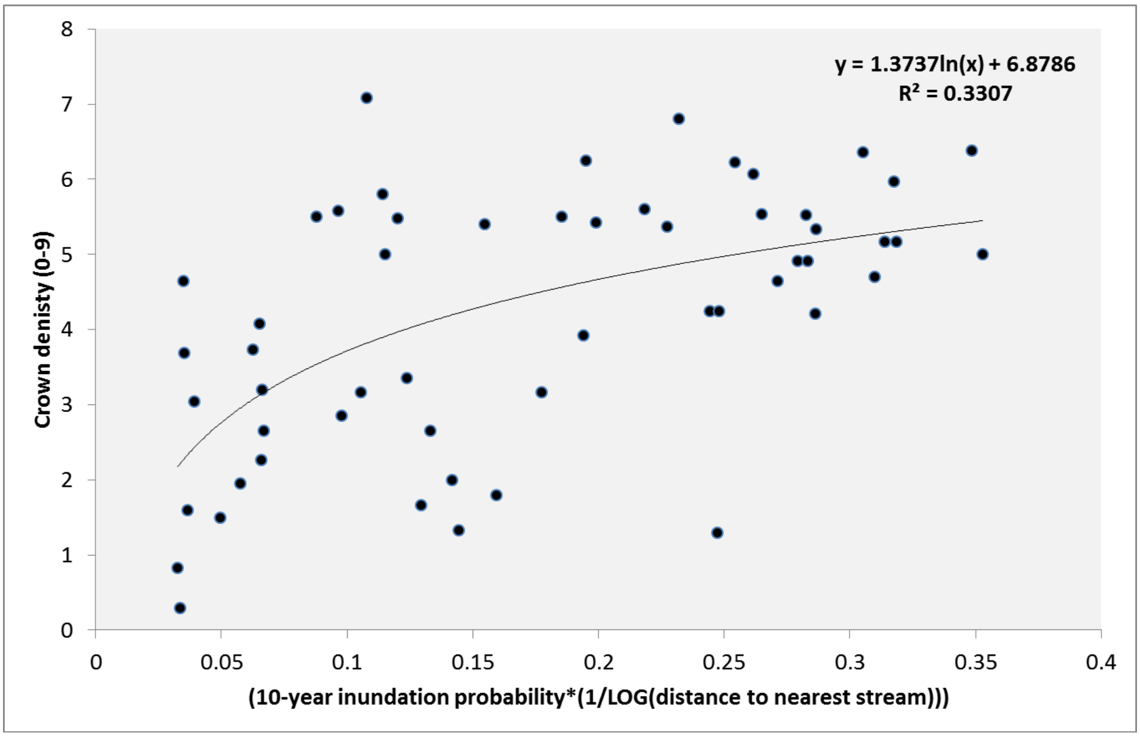


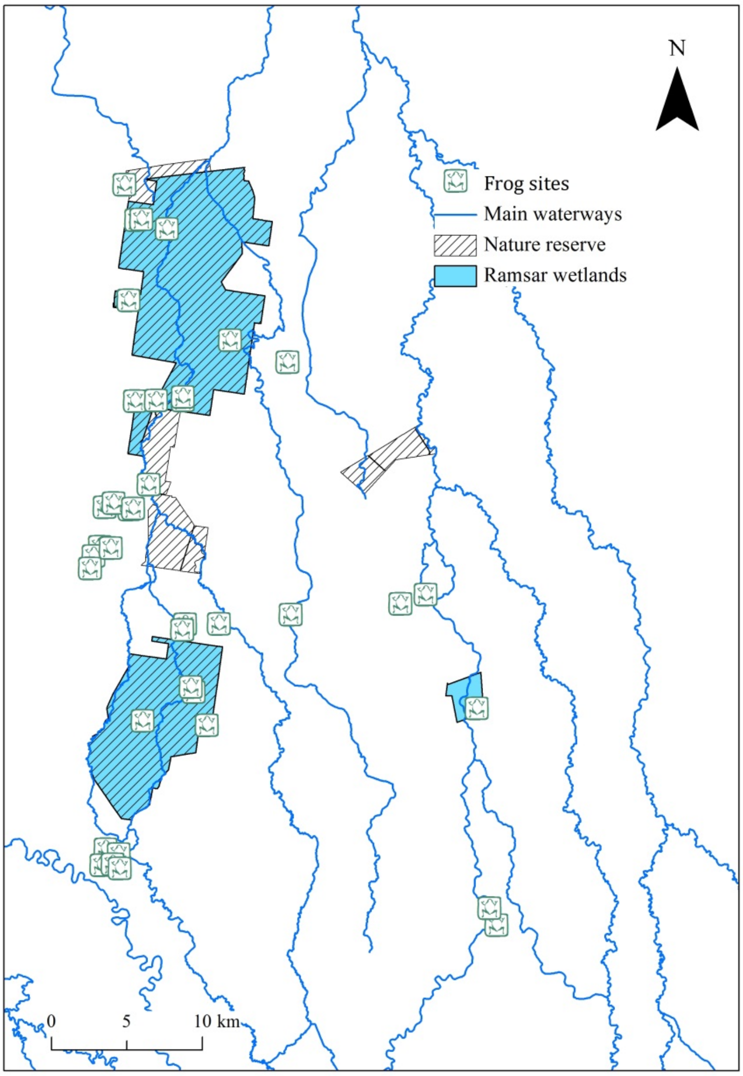
Figure 36: Modelled relationship between crown density and inundation probability and distance to nearest stream.



Frogs

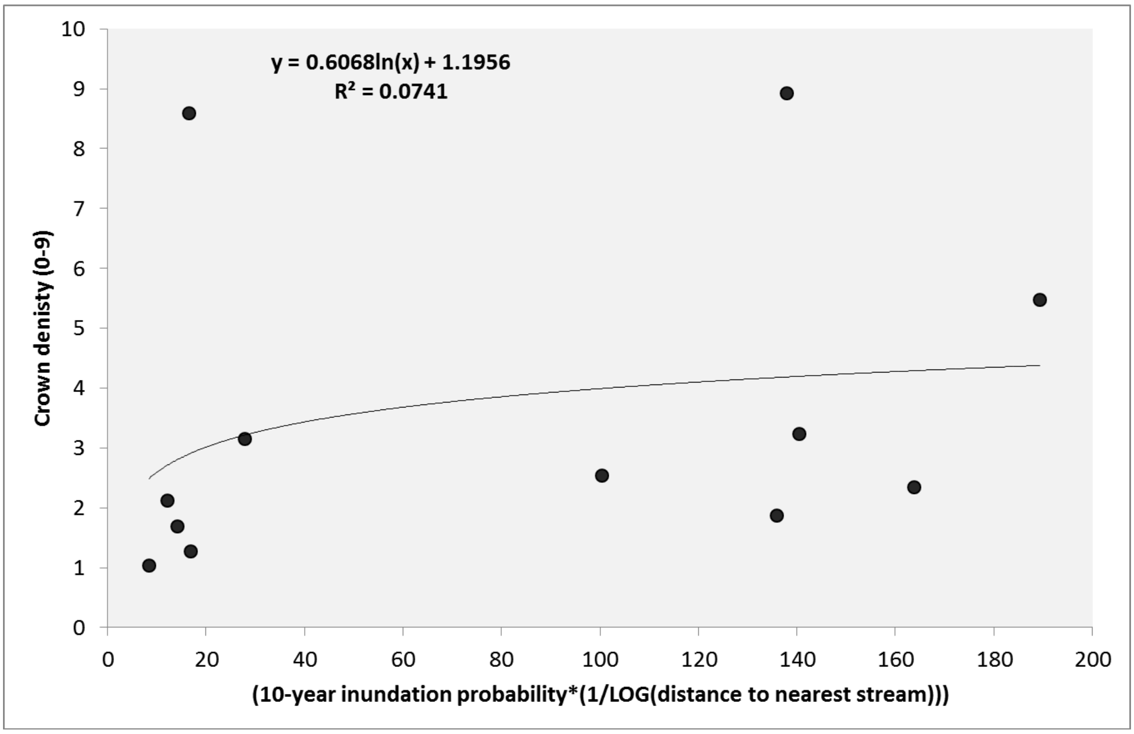
Frog abundance estimates rely on work carried out by Jo Ocock as part of her PhD dissertation. Frog populations in the Macquarie Marshes were surveyed interchangeably across 41 sites within 125,000 ha of the wetland (Figure 37). Sites were surveyed monthly during the spring flooding period over the course of three seasons from September 2009 to March 2011. All frogs were identified and counted during nocturnal transects using visual and auditory encounter surveys (VAES).

Figure 37: Frog sampling sites across the Macquarie Marshes



Average abundances for each of the three seasons were estimates by controlling for visitation effort. A logit relationship between abundance estimates and total spring flows at Marebone gauge was examined (Figure 38).

Figure 38: Modelled relationship between frog monthly abundances and total 3-month flow measured in Marebone.



Invertebrates

Invertebrate abundance estimates rely on work carried out by Jenkins et al (2012). A total of 560 microinvertebrate bilge samples were processed as part of this UNSW and NSW Office of Water project and 100 benthic core samples. In addition, eighty sweep net samples were processed, building on a dataset comprising 639 macroinvertebrate samples collected with small benthic corers and sweep nets during an Environmental Trust project. Samples were collected from creeks (regulated and temporary) during a wet period in 2003 and from creeks and floodplain after the environmental allocations in 2005 and 2009. Average abundances was estimated separately for each of the sampled creeks and controlled for sampling effort for each of the five years. We focused our analysis on Bora Creek sampling site (Figure 39), which has a shorter history of regulation and has been observed to contain the healthiest invertebrates and macroinvertebrates communities (Jenkins et al., 2012). A logit relationship between abundance and richness estimates and total spring flows (total over previous 3 months prior to sampling) at Marebone gauge was examined (Figure 40 and

Figure 41).

Figure 39: The Macquarie River and creeks within the Macquarie Marshes

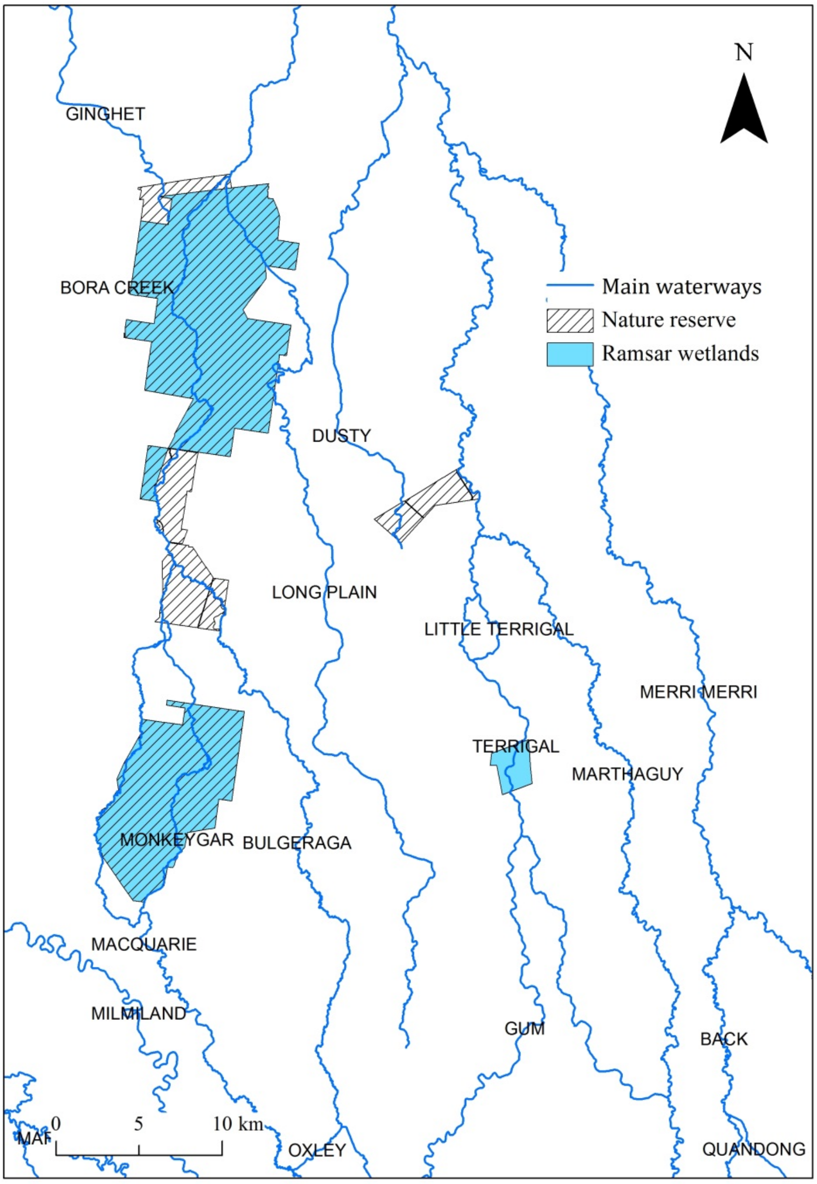


Figure 40: Modelled relationship between invertebrate abundances and total spring flows across the Macquarie Marshes.

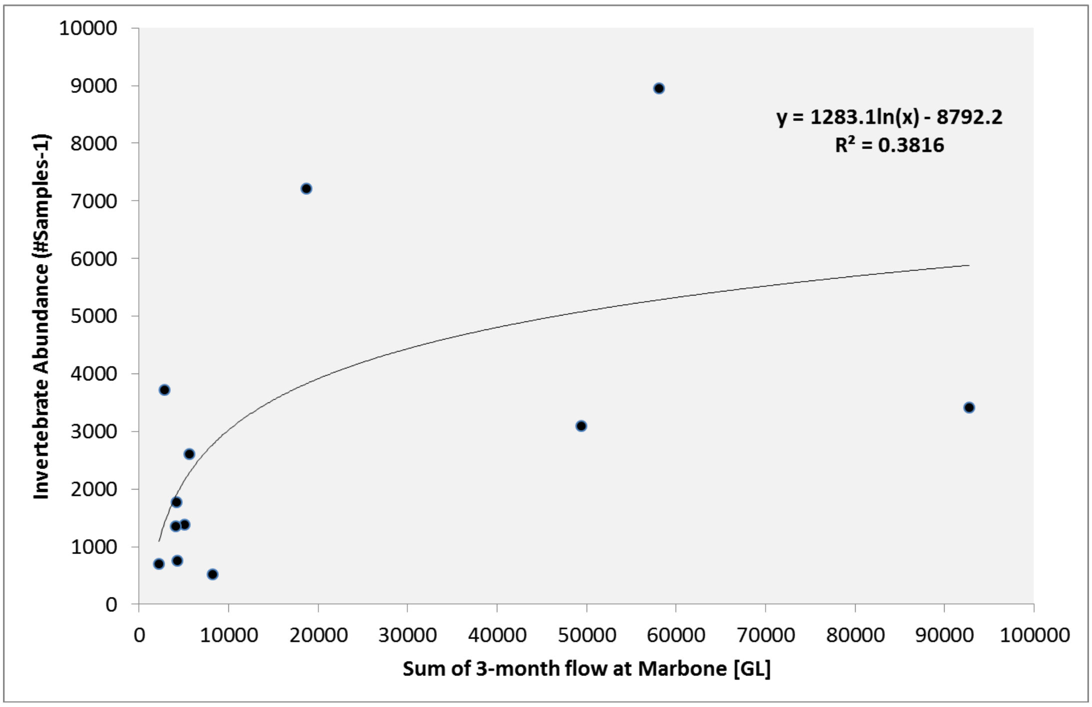
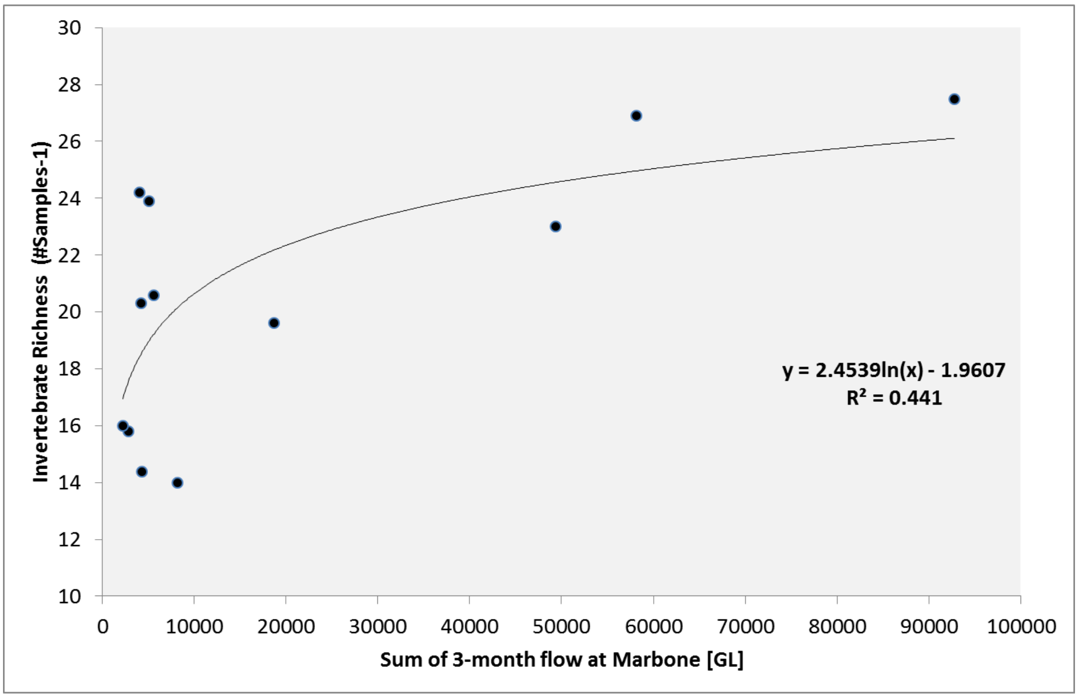


Figure 41: Modelled relationship between invertebrate richness and total spring flows across the Macquarie Marshes.



Process model

We constructed a Bayesian Belief Network (BBN) using the software package, Netica (NORSYS, 2011). This was a graphical model representing the key factors of a system (nodes) and their conditional dependencies (Varis, 1997, Korb and Nicholson, 2004, Jensen and Nielsen, 2007). Within the BBN, dependent or 'child node' (i.e., colonial waterbird breeding) were connected with direct links to 'parent node' (i.e., water flows). The network was then populated with conditional probability tables (CPTs), associated between each child and parent node. We populated CPTs using modelled ecological responses of colonial waterbird breeding, vegetation communities persistence probability, frogs abundance, epicormic growth of river red gums, and invertebrates abundance (sections 3.3.2-3 and current) with total spring flow volumes at Marebone gauge to form a comprehensive process model of the Macquarie Marshes ecosystem (Figure 41). The BBN enables estimating the likelihood of the state of a parameter (e.g., breeding), given the states of input parameters such as total annual spring flow (Figure 41) and climate change (Figure 42).

Figure 42: Bayesian belief network (BBN) constructed for key ecological assets of the Macquarie Marshes. The network provides conditional probability of ecological response for each ecological assets and total spring flow at Marebone.

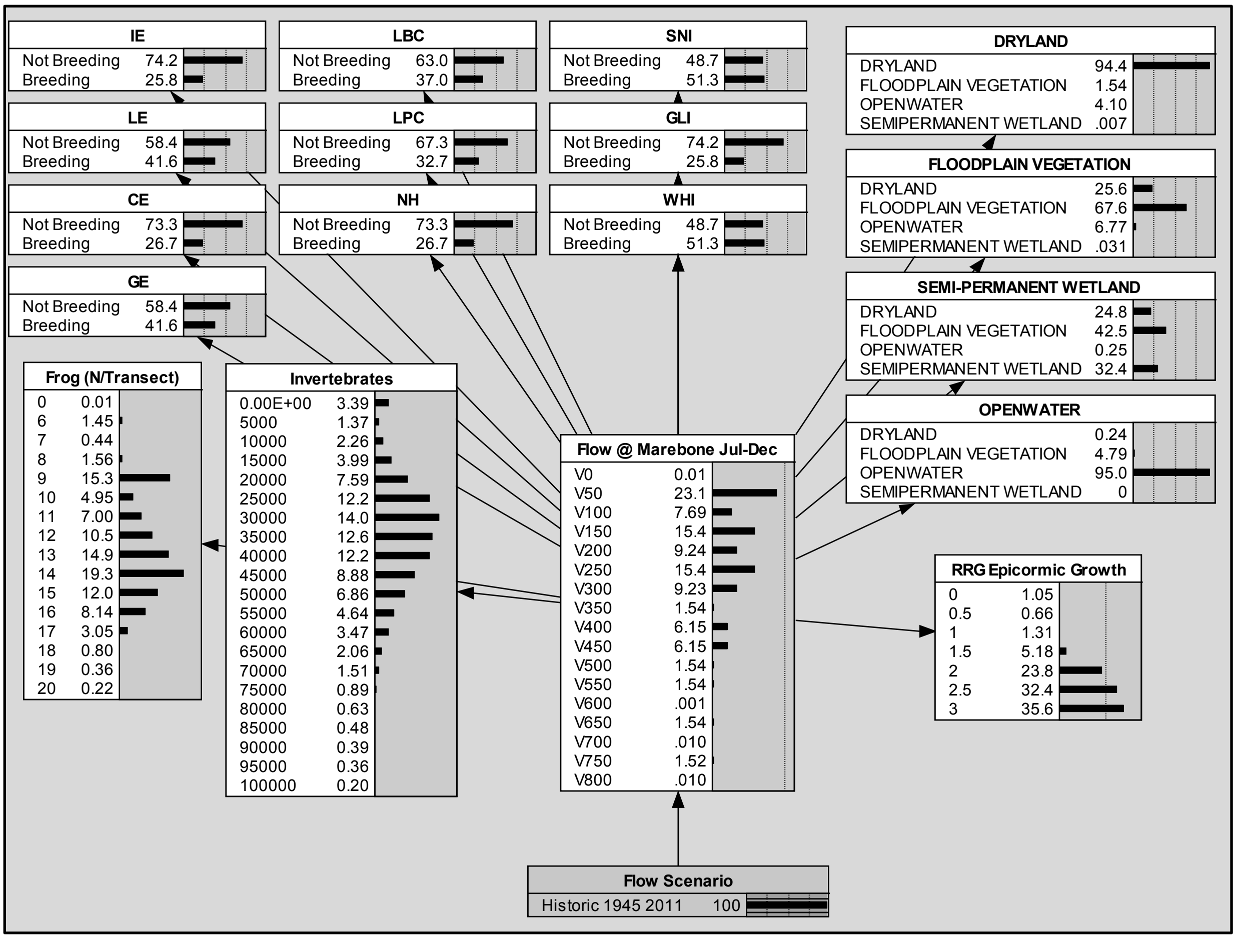
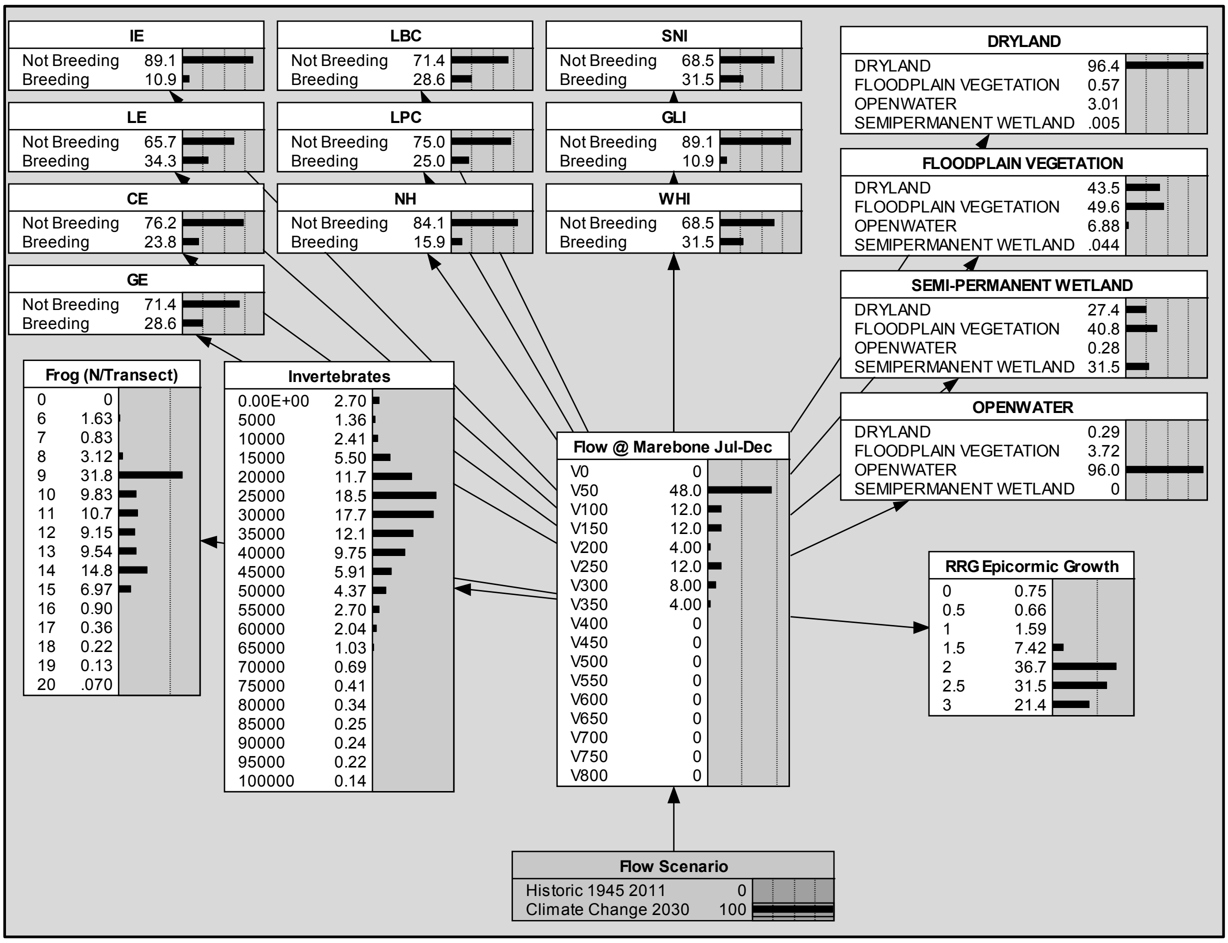


Figure 43: Bayesian belief network (BBN) constructed for key ecological assets of the Macquarie Marshes. The network provides conditional probability of ecological response for each ecological assets and total spring flow at Marebone under projected dry climate change state for 2030 (-38% reduction in flow volumes, Source: CSIRO (2008)).



3.3.5. Conclusions

Protected areas are fundamentally established to conserve special and specific values of ecological, socio-economic and\or cultural importance. Their success as a tool for conservation relies on the way in which they are managed to protect those values against threats (Hockings et al., 2006). Threats to conservation values are many, varied, and range in scale from global (e.g., climate change) through regional (e.g., agricultural development and river damming) to more localised (e.g., invasive species),(Secretariat, 2010). Generally, as the scale of threat increases, the ability of managers and stake holders to mitigate or influence these within a Protected area decreases (Cusworth and Franks, 1993). Review and identification of all key values and threats is a vital step for conservation management. As protected areas conserve a great number of values (Janishevski et al., 2008) but are limited by resources (James et al., 1999, Ferraro and Pattanayak, 2006), it is often necessary for managers and stakeholders to select those which should be given priority in planning, management, and monitoring(Watson et al., 2011). Prioritisation of values can be a difficult task to achieve as each can hold significance at varying scales (e.g., global, national, catchment) and may be exposed to varying degrees of threat. One strategy is to define key values based on ecological communities or system, complemented by selection of species with unique ecological requisites not captured in the conservation of the communities or ecological systems in which they are embedded (Poiani et al., 1998, Parrish et al., 2003). Safeguarding these against threats should ensure integrity of ecosystem functions and the ecological character as a whole within protected areas.

For managers to shortlist a set of conservation targets, they must first formalise an ecological model depicting the key ecological components and the underlying processes of cause and effect (Maddox et al., 2001). As the model represents the important biological processes in the ecosystem, it therefore identifies what attributes of the ecosystem managers should monitor. Key ecological attributes can have a range of desired characteristics including: be easily monitored, sensitive to stress, predictable, anticipatory, and integrative (Dale and Beyeler, 2001). This framework is dependent on the premise that the system has a number of identifiable Key ecological attributes that sustain conservation targets and maintain their composition, structure, and function. Once key ecological attributes have been identified, monitoring and management can be integrated within a strategic adaptive management framework. In essence, strategic adaptive management recognises the inherent uncertainties of dynamic and unpredictable ecosystems but tests these uncertainties, progressively improving management (Kingsford et al., 2011a). Strategic adaptive management brings together the disciplines of management and decision science so that management interventions are designed to elicit scientifically measurable results that are analysed to inform future management decisions.

Ecological models are a critical component of strategic adaptive management as they help represent our beliefs about ecosystem properties and dynamics, and project the consequences of how the system responds to management. Strategic adaptive management seeks to resolve this kind of model uncertainty over time through iterative updating of the plausibility of competing models. Here we developed models of ecological cause-and-effect for key assets of the Macquarie Marshes under alternative water management regimes and plausible climate change scenarios, to form the basis of a process model for the Macquarie Marshes. The process models is used summarise the current understanding of system dynamics and the anticipated response of the system to management and climate change scenarios. The model captures the cause-and-effect processes that drive anticipated ecological indicators and their drivers of change under current knowledge. Ultimately, the process models can be used to inform a strategic adaptive management framework currently being developed for the Macquarie Marshes (Kingsford, 2011, Kingsford and Biggs, 2012a).

3.4. Policy and legislation

3.4.1. Introduction

Many different legislative and policy frameworks interact and focus on management of wetlands, particularly wetlands of international importance and their water supply (i.e. rivers) within a catchment context. There is a strong commitment by many governments to implementing adaptive management but this can be difficult given there are policies and legislative processes already in place which are the ‘operating space’ for environmental management. We discuss policy and legislation implications of a strategic adaptive management framework for the Macquarie Marshes. Specifically, we identify alignment of the adaptive management approach with current policies and processes and the potential for integration of these policies and planning structures into a cohesive SAM framework at different government and spatial scales.

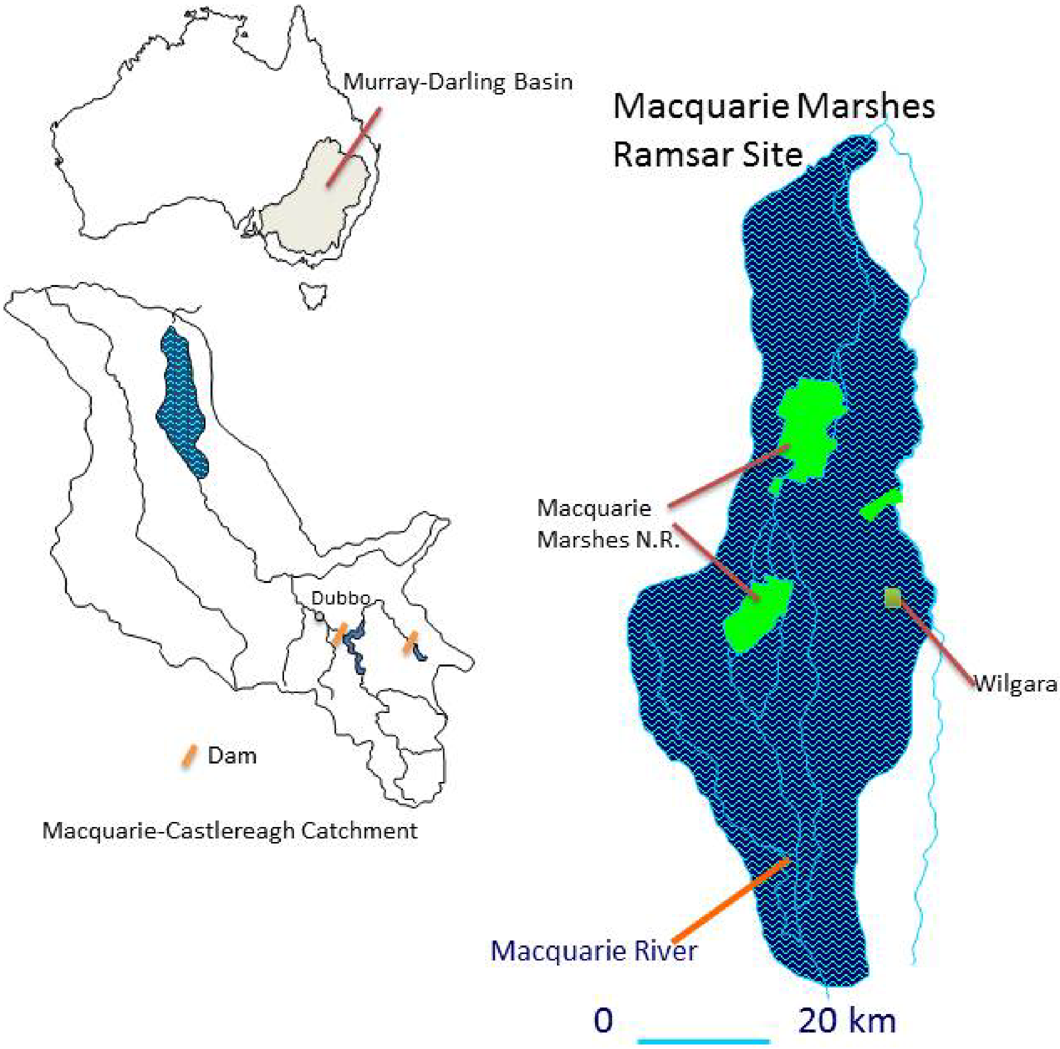
All relevant legislation and governance frameworks were considered: State, Commonwealth, and international levels. We particularly focused on recent changes to the governance of the Murray-Darling Basin, implemented through the Water Act 2007 and its instrument the Murray-Darling Basin Plan, which usher in a new era of water policy that aims to rehabilitate the basin’s ecosystems and address overexploitation and mismanagement of water resources. We begin with background information on the Macquarie Marshes and their ecological significance and then briefly review the governance framework for water policy in the Murray-Darling Basin. The next section presents the review of current legislation and policy frameworks for the Macquarie Marshes, providing the basis for an evaluation of the potential for integrating these policies into a coherent Strategic Adaptive Management framework, which incorporates climate change adaptation.

3.4.2. Macquarie River and Marshes: An ecosystem at risk

The Macquarie River is a highly regulated river in the Murray–Darling Basin, within the Macquarie-Bogan catchment (74,634 km^2, (Kingsford et al., 2004). Its headwaters rise on the western side of the Great Dividing Range, south-east of Bathurst, and it then flows for about 500 kilometres north-west and north before joining the Barwon–Darling River in northern New South Wales. The catchment supports diverse agricultural activities including intensively farmed and broadacre crops, as well urban centres and small rural service centres.

The river is primarily regulated by Burrendong Dam, near Wellington, which impounds flows of the Macquarie River for flood control and irrigation (Figure 44). The Macquarie River eventually inundates the Macquarie Marshes (Figure 44), a large, diverse complex of wetland vegetation communities, which provide essential habitat for many species of organisms. The marshes support some of the largest waterbird breeding events in Australia and serve as an important refuge for wildlife in drought periods ((Kingsford and Johnson, 1998, Kingsford and Auld, 2005b). They are one of the largest remaining inland semi-permanent wetlands in southeastern Australia. The ecological and cultural values of the marshes are recognised at all levels of Australian government, with about 10% of the wetland area designated as a Nature Reserve (22,300 ha) under NSW legislation. The Northern and Southern Nature Reserve in the marshes and a private landholding (Wilgara) were recognised as a Wetland of International Importance under the international Ramsar Convention on Wetlands in 1986, making up 18,726 ha. Table 25 shows the criteria for Ramsar listing which are met by the Macquarie Marshes.

Figure 44: Location of Macquarie Catchment and Macquarie Marshes Ramsar site



The marshes are primarily dependent on flows from the Macquarie River and its tributaries (Kingsford and Johnson, 1998, Department of Environment Climate Change and Water NSW, 2010a, Department of Environment Climate Change and Water NSW, 2010b, Ralph and Hesse, 2010, Ren et al., 2010, Thomas et al., 2011b). Since significant flows have been diverted for irrigation after regulation by upstream dams on the Macquarie River, there have been significant impacts on the Macquarie Marshes ecosystem, which requires frequent and extensive flooding. Since the late 1970s, there has been a marked decline in the area of the marshes that receives adequate flood frequency and duration (Thomas et al., 2011b). Due to regulation of flows and extraction, large areas are experiencing encroachment by terrestrial vegetation, replacing flood-dependent vegetation with significant areas of river red gum in poor condition (Bowen and Simpson, 2008, Steinfeld and Kingsford, 2011, Thomas et al., 2011b). Less than half of the 72,000 hectares of semi-permanent wetland mapped in the marshes is now in fair or better condition, and many areas are still in decline (Department of Environment Climate Change and Water NSW, 2010b). Degradation of vegetation has not been the only impact of reduced flooding in the marshes. River regulation was estimated to decrease breeding colony size of colonial waterbirds by about 100,000 pairs every 11 years, based on the strong relationship between flow and breeding of colonial waterbirds (Kingsford and Johnson, 1998). By the early 2000s, nest counts in breeding colonies were just as low after ten years of drought, prolonged by upstream extractions and regulation. However, recent flood events in the past two years have seen the largest breeding events since the early 1980s (OEH, unpubl. data). During intense dry periods, the marshes also serve as an important refuge for native fish species which rely upon natural patterns of wetting and drying for survival, and flow regulation of the Macquarie River and its tributaries has led to a decline in the health of native fish populations (Rayner et al., 2009).

Table 25: Ramsar nomination criteria fulfilled in the Macquarie Marshes (OEH, 2013a)

Ramsar nomination criteria	Macquarie Marshes
1 – Representative of unique wetlands	One of the largest remaining inland, semi-permanent wetlands in the Murray-Darling Basin with a high diversity of wetland types
2- Threatened species or ecological communities	Supports found internationally listed threatened species, and five nationally threatened species under the EPBC Act and nationally endangered Coolibah blackbox woodland community.
3 – Populations of plants and/or animals important for maintaining biodiversity of a particular bioregion	Contains a variety of habitat types including river red gum (*Eucalyptus camaldulensis*) woodlands, common reed (*Phragmites australis*) reedbeds, and water couch marsh (*Paspalum distichum*). The Ramsar site is also the limit of the range for several plant and animal species.
4 – Supports species at a critical stage of their life cycle or provides refuge in adverse conditions	Highly significant habitat for colonially breeding waterbirds including straw-necked ibis *(Threskiornis spinicollis), magpie geese* ((*Anseranas semipalma*), intermediate egret *(Ardea intermedia), rufous night heron (Nycticorax caledonicus), and royal spoonbill (Platalea regia) and a diversity of other waterbirds.*
5 – Supports 20,000 or more waterbirds	Regularly support more than 20,000 waterbirds and over 500,000 in large floods. Sixteen colonial nesting waterbird species have been recorded breeding in the Macquarie Marshes.
8 – Food source, nursery or migration path for fish	The native fish community in the Marshes comes from adjacent main channels. Native fish move out of the main channel habitats into the floodplain to breed and spawn during high flows.

As a result of these impacts on the Macquarie Marshes ecosystem, the Commonwealth Government issued a notification under Article 3.2 of the Ramsar Convention of a 'likely change' in ecological character as a result of anthropogenic changes in 2009 (Australian Government, 2012). This was attributed to decline in the health of wetland vegetation and waterbird breeding as a result of river regulation. This notification is essentially an indication that the Commonwealth and NSW Governments have probably not achieved the aims of the Ramsar Convention to maintain the ecological character of this listed wetland through wise use and effective management. Recent increases in environmental flows through the purchase of water from the irrigation industry may have addressed some of the degradation.

A major contributing factor was the failure of governance frameworks to address the complex needs of the wetland ecosystem over a long period. Strategic adaptive management could provide such an approach, but it requires cooperation and coordination of the multiple levels of policy and legislation that apply to the Macquarie Marshes. The next sections review the current governance structures, beginning with some background on water policy in the Murray-Darling Basin.

3.4.3. Background on governance framework for water policy in the Murray-Darling Basin

The rivers and floodplains of the Murray-Darling Basin provided resources for the European colonists of Australia, fostering the development of Australia's first great transport network and the agricultural industry, beginning with wool but later fostering irrigation across the Murray-Darling Basin. Australian colonies (New South Wales, Victoria, South Australia) developed irrigation-based settlements in the Murray-Darling Basin predominantly during the early 20th century. Each colony pursued its own interest, conflicting with others (Connell, 2007). As the least populous and poorest colony, South Australia was most concerned about New South Wales and Victoria taking more than their fair share of water from the River Murray, which it relied upon for transport and agriculture. New South Wales felt it 'owned' the water in the Murray but was threatened by the rapid development of irrigation on the tributaries in Victoria that supplied most of the flow, while Victoria wanted reliable water for its irrigation communities developing on the Murray (Connell, 2007). Rather than applying riparian law inherited from Britain, governments legislated to have direct control over water management, allowing them to create entitlements that varied with climate and subsequent availability of stored water, essentially providing a proportion of available flow each year rather than a fixed volume for diversion, predominantly downstream of major storages (Connell, 2007).

At the turn of the century, colonies became states through Federation, under the Commonwealth of Australia. Power over water policy was delegated largely to individual states through section 100 of the Constitution, which gave power to the states for irrigation development. This meant that management of the Murray-Darling Basin waters was contingent on cooperation between New South Wales, Victoria, and South Australia. At this time, Australia experienced a severe drought from 1901-02, the Federation Drought. In response, a non-government conference in Corowa 1902 called for government action to equitably manage the waters of the Murray. Negotiations following this conference eventually led to the River Murray Waters Agreement in 1915 between the Commonwealth, NSW, VIC, and SA Governments. This agreement set out basic conditions for sharing of the Murray and its tributaries, and established the River Murray Commission to own and manage dams, weirs, and locks on the Murray (Quiggin, 2001).

The overall paradigm of water development in Australia during most of the 20th century can be described as a 'magic pudding' model in which growth in demand over time was met by additional supply through increased capture and development of water resources (McKay, 2005). In the Murray-Darling Basin in the mid-20th century, protectionist policies favoured expansion of irrigation, subsidies, and major infrastructure investments in the MDB to drive an expansionary water economy (Quiggin, 2001). The Murray-Darling Basin has most of its annual runoff diverted, storage capacity in the dams exceeds mean annual runoff, and 87% of divertible resources extracted (Kingsford, 2000), allowing for the storage of 130% of average flow (CSIRO, 2008d). Between 1940 and 1990, the capacity of major dams in Australia grew tenfold (Connell, 2007, Kingsford et al., 2011c). Water use in the Border Rivers region of Australia rose by more than 2,700% between 1969 and 1991, mostly to irrigate cotton crops. This was made possible through Government-funded dam building projects (Kingsford, 1999, Kingsford, 2000).

By the 1970s and 80s, there was growing concern about the environmental problems which had emerged as pressure on surface or rivers and groundwater systems increased , and at around the same time, irrigation communities began to demand more control over the water delivery systems, essential to their industries and livelihoods(Connell, 2007).

In 1980s-1990s, Australia was in a period of wide institutional reform, which also included reforms to MDB governance. Water management was moving from public utility model towards a more coordinated approach for Basin-wide management, and an expanded brief for management agencies to deal with environmental problems. Water managers had to take growing environmental concerns into consideration, as well as changing definitions of the public interest and political mobilization of sectors of society that had not been involved in the past (Connell, 2007). The 1987 *Murray-Darling Basin Agreement* and *Murray-Darling Basin Act 1993* sought 'to promote and coordinate effective planning and management for the equitable and sustainable use of the water, land and other environmental resources of the Murray-Darling Basin. This Act established the Murray-Darling Basin Ministerial Council, Murray-Darling Basin Commission and the Community Advisory Committee as new coordinating bodies to take on the increasingly complex task of managing the basin's resources while balancing the needs of the environment and multiple stakeholders. In 1994, the Council of Australian Governments (CoAG) agreed on reforms to the water industry for sustainable and efficient use of water resources. This aligned water policy with National Competition Policy, reinforcing a preference for market-based solutions through market-based solutions to environmental problems (such as pricing mechanisms and water trading) but also promoting the inclusion of Ecologically Sustainable Development (Australia, 1992) principles into legislation and water policy. This meant establishing clear provisions of water for the environment (CoAG, 1994). In 1998, a permanent upper limit to diversions in the MDB was established. Known as the Cap, this limit was defined as the volume of water that would have been diverted under 1993-1994 levels of development (Quiggin, 2000) but it was inconsistently applied across the States. Queensland had later development thresholds and floodplain harvesting was not adequately regulated (Steinfeld and Kingsford, 2011).

The next major development in Australian Water Policy was the 2004 *National Water Initiative*, under CoAG, which can be described as a new philosophical approach to water management, articulating key national principles for water management and providing a primary policy statement for the compliance of all water-related policy and legislation (Connell et al., 2005, Hussey and Dovers, 2006). In 1994, CoAG recognised that the environment was a legitimate user of water. In 2004, CoAG agreed to the National Water Initiative (NWI), which will chart the future responsibilities and progress towards sustainable management of the nation's rivers and aquifers. Provisions in the intergovernmental agreement on the NWI commit parties (all States and Territories apart from Tasmania and Western Australia) to identify, protect and manage high-conservation-value rivers and aquifers and their dependent ecosystems. The key imperatives of the National Water Initiative were to "increase the productivity and efficiency of Australia's water use, the need to service rural and urban communities, and to ensure the health of river and groundwater systems by establishing clear pathways to return all systems to environmentally sustainable levels of extraction" (COAG, 2004). The National Water Initiative encouraged further reforms in State and Commonwealth-level legislation, promoting market-based reforms and environmentally sustainable levels of extraction. For the Murray-Darling Basin, these reforms came with the *Water Act 2007*, which created a Commonwealth-level body, the Murray-Darling Basin Authority tasked with establishing a strategic plan for the whole Basin, based on sustainable levels of extraction from surface and groundwater resources. This policy framework is reviewed in more detail later.

3.4.4. Relevant legislation and policy for the Macquarie Marshes

This section begins the review of legislation and policy frameworks relevant to the Macquarie Marshes, through an overview of the relevant legislation, including conservation goals, scale, and incorporation of adaptive management (Table 26). After this initial review, the specific implementation of these policies within the Macquarie Marshes and potential for integration into a Strategic Adaptive Management framework are discussed.

Table 26: Legislation relevant to the Macquarie Marshes, its relevant scale, key conservation and natural resource management goals and reference to adaptive management

Legislation	Conservation and natural resource management goals	Scale	Adaptive management
EPBC Act 1999	• providing for the protection of the environment, especially matters of national environmental significance • conserving Australian biodiversity • providing a streamlined national environmental assessment and approvals process • enhancing the protection and management of important natural and cultural places • controlling the international movement of plants and animals (wildlife), wildlife specimens and products made or derived from wildlife • promoting ecologically sustainable development through the conservation and ecologically sustainable use of natural resources	Commonwealth	Not mentioned
Water Act 2007	Ensure that Basin water resources are managed in an integrated and sustainable way; MDBA will oversee water planning considering the Basin as a whole, rather than state by state, for the first time; establishes limits on sustainable water extractions, environmental watering plan, establishes the Commonwealth Environmental Water Holder. Also - "To give effect to relevant international agreements (to the extent to which those agreements are relevant to the use and management of the Basin water resources) and, in particular to provide for special measures, in accordance with those agreements, to address the threats to Basin water resources"	Commonwealth	Adaptive management principles apply to Murray Increased Flows

Table 26 (continued): Legislation relevant to the Macquarie Marshes, its relevant scale, key conservation and natural resource management goals and reference to adaptive management.

Legislation	Conservation and natural resource management goals	Scale	Adaptive management
Murray-Darling Basin Plan 2012	Key environmental assets are protected and improved, adequate water to sustain ecological resilience during drought periods; enough flow to keep Murray mouth open to the sea in most years; the river system transports salt and nutrients to the sea; adequate water quality to sustain key uses. Based on an environmentally sustainable level of take from the river system.	Commonwealth	Adaptive management should be applied in the planning, prioritisation and use of environmental water (Principle 8). Adaptive Management is defined in the Murray-Darling Basin Plan as including the following steps: (a) setting clear objectives; (b) linking knowledge (including local knowledge), management, evaluation and feedback over a period of time; (c) identifying and testing uncertainties; (d) using management as a tool to learn about the relevant system and change its management; (e) improving knowledge
National Parks and Wildlife Act 1974	An Act to consolidate and amend the law relating to the establishment, preservation and management of national parks, historic sites and certain other areas and the protection of certain fauna, native plants and Aboriginal objects. Applies to conservation of nature (habitat, ecosystems, and ecosystem processes), landforms of significance, landscapes and natural features of significance, cultural heritage values. Objectives to be achieved according to ESD principles.	NSW	Statutory management plans are reviewed/revised every 10 years, based on appropriate research and monitoring. The current Macquarie Marshes Nature Reserve Plan of Management was gazetted in 1993 and is yet to be publically reviewed/ revised.

Table 26 (continued): Legislation relevant to the Macquarie Marshes, its relevant scale, key conservation and natural resource management goals and reference to adaptive management.

Legislation	Conservation and natural resource management goals	Scale	Adaptive management
Fisheries Management Act 1994	The FM Act aims 'to conserve, develop and share the fishery resources of the State for the benefit of present and future generations with objectives to: - conserve fish stocks and key fish habitats, and threatened species, populations and ecological communities of fish and marine vegetation, and - promote ecologically sustainable development, including the conservation of biological diversity, and, consistently with those objects: - promote viable commercial fishing and aquaculture industries, and - promote quality recreational fishing opportunities, and - appropriately share fisheries resources between the users of those resources, and - provide social and economic benefits for the wider community of New South Wales.	NSW	Not mentioned, listings of threatened aquatic species are included in the FMA following the provisions with the Threatened Species Conservation Act and periodically reviewed at least every 2 years.
Threatened Species Conservation Act 1995	• Conserve biological diversity and promote ecologically sustainable development • Prevent extinction and promote recovery of threatened species, populations and ecological communities • Protect critical habitat of threatened species populations and ecological communities that are endangered • Eliminate or manage processes that threaten survival or evolutionary development of threatened species, populations and ecological communities (key threatening processes) • Ensure impact of any action affecting threatened species, populations and ecological communities is properly assessed • Encourage the conservation of threatened species, populations and ecological communities by the adoption of measures involving co-operative management.	NSW	Not mentioned explicitly, although the lists must be kept under review by the Scientific Committee which must determine, at least every 2 years if changes are necessary. Threat abatement plans are mandatory for listed species, ecological communities, and key threatening processes. This includes the key threatening process of *Alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands*, although no threat abatement plan exists for this ktp.

Table 26 (continued): Legislation relevant to the Macquarie Marshes, its relevant scale, key conservation and natural resource management goals and reference to adaptive management.

Legislation	Conservation and natural resource management goals	Scale	Adaptive management
Water Management Act 2000	To provide for the sustainable and integrated management of the water resources of the State for the benefit of both present and future generations and • To apply ESD principles • To protect, enhance and restore water sources, their associated ecosystems, ecological processes and biological diversity and their water quality • To recognize and foster the significant social and economic benefits to the State that result from sustainable and efficient use of water, including: Benefits to the environment; Benefits to urban communities, agriculture, fisheries, industry and recreation; and Benefits to culture and heritage • To integrate the management of water sources with the management of other aspects of the environment, including the land, its soil, its native vegetation and its native fauna	NSW	The principles of adaptive management should be applied, which should be responsive to monitoring and improvements in understanding of ecological water requirements. Water management plans are valid for 10 years but subject to audit/review every 5 years, based on more accurate scientific knowledge (e.g. to provide additional water to the environment due to findings that the previous amount was inadequate). As of 2019, they will need to be compliant with the Murray-Darling Basin Plan.
Catchment Management Authorities Act 2003	NRM planning at catchment level; decision making according to catchment issues; apply sound scientific knowledge for a fully functioning and productive landscape; involve communities in decision making and make best use of knowledge and expertise	NSW	Catchment management plans kept under periodic review, at least every 5 years. The Central West Catchment Action Plan is based on resilience thinking and includes adaptive management: The parts of the CAP identified as requiring adaptive management are: thresholds of potential concern; state and transition models; and program logics (actions, management targets and catchment goals)

Table 26 (continued): Legislation relevant to the Macquarie Marshes, its relevant scale, key conservation and natural resource management goals and reference to adaptive management.

Legislation	Conservation and natural resource management goals	Scale	Adaptive management
Environmental Planning and Assessment Act 1979	Provides a system of planning and assessment for New South Wales. Objects include: proper management, development, and conservation of natural and artificial resources including agricultural land, natural areas, forests, minerals, water, cities, towns and villages; protection of the environment including threatened species, populations, and ecological communities; sharing responsibility for environmental planning between the different levels of government; and increased opportunity for public involvement and participation in environmental planning and assessment.	NSW	Not mentioned
Local Government Act 1993	To provide the legal framework for an effective, efficient, environmentally responsible and open system of local government in New South Wales. To require councils and councilors and council employees to have regard to the principles of ecologically sustainable development in carrying out their responsibilities. Section 428A – State of the environment reports must be prepared as part of each annual report in the year in which an ordinary election of councillors is held.	NSW – Local Government	Not explicitly mentioned, but mandatory state of the environment reporting provides valuable data and input into an adaptive management process.

The ***EPBC Act 1999*** provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places — defined in the EPBC Act as matters of national environmental significance. This includes listed Ramsar Wetlands. The Act also requires the Australian Government to list and protect migratory bird and animal species listed under the Convention of Migratory Species of Wild Animals, Japan-Australia Migratory Bird Agreement, and China-Australia Migratory Bird Agreement and Republic of Korea – Australia Migratory Bird Agreement. This means that they are subject to the same planning processes and protection mechanisms as other matters of national environmental significance.

The EPBC Act works through multiple mechanisms including listing of threatened species and ecological communities; designation of matters of national environmental significance and requirements of landowners, developers, industry, farmers, councils, state and territory agencies, and Commonwealth agencies to determine if actions potentially have significant impact on matters of national environmental significance.

Within the Macquarie River catchment, the *EPBC Act 1999* relevance relates to potentially deleterious anthropogenic impacts on the Ramsar-listed Macquarie Marshes, and any nationally listed threatened or vulnerable flora or fauna species and migratory species. Also, the Act needs to consider key threatening processes. It also obliges the Australian Government to protect the ecological character of Ramsar wetlands and manage them in accordance with Schedule 6 of the *Environment Protection and Biodiversity Conservation Regulations 2000*. This requires management of a declared Ramsar wetland in Australia, including description and maintenance of the ecological character of the declared wetlands, followed by formulation and implementation of management which maintains the ecosystem. The Macquarie Marshes Nature Reserve Ramsar site supports four internationally endangered or vulnerable species and three nationally endangered or vulnerable species listed in the *EPBC Act* (Department of Environment Climate Change and Water NSW, 2010a). There are also 14 listed migratory species recorded for the Macquarie Marshes (Table 27).

Table 27: IUCN and EPBC –listed threatened and migratory species in the Macquarie Marshes

Species	Status	Listing
Australasian bittern *Botaurus poiciloptilus*	(Endangered)	IUCN Red list 2008
Superb parrot *Polytelis swainsonii*	(Vulnerable)	IUCN Red list 2008 EPBC Act
Black-chinned honeyeater *Melithreptus gularis gularis*	(Vulnerable)	IUCN Red list 2008
Silver perch *Bidyanus bidyanus*	(Vulnerable)	IUCN Red list 2008
Australian painted snipe *Rostratula australias*	(Vulnerable)	EPBC Act
Aromatic pepper-cress *Lepidium hyssopifolia*	(Endangered)	EPBC Act
Murray cod *Maccullochella peeli peeli*	(Vulnerable)	EPBC Act
Common sandpiper *Actitis hypoleucos*	Migratory	EPBC Act
Eastern Great Egret *Ardea modesta*	Migratory	EPBC Act
Curlew sandpiper *Calidris alba*	Migratory	EPBC Act
Sharp-tailed sandpiper *Calidris acuminata*	Migratory	EPBC Act
Red-necked stint *Calidris ruficollis*	Migratory	EPBC Act
Japanese snipe, Latham's snipe *Gallinago hardwickii*	Migratory	EPBC Act
Black-tailed godwit *Limosa limosa*	Migratory	EPBC Act
Bar-tailed godwit *Limosa lapponica*	Migratory	EPBC Act
Glossy Ibis *Plegadis falcinellus*	Migratory	EPBC Act
Caspian tern *Sterna caspia*	Migratory	EPBC Act
Wood sandpiper *Tringa glareola*	Migratory	EPBC Act
Common greenshank *Tringa incana*	Migratory	EPBC Act
Marsh sandpiper *Tringa stagnatilis*	Migratory	EPBC Act

The ***Water Act 2007*** supports sustainable management of the water resources of the Murray-Darling Basin and other matters of national interest in relation to water and water information and related purposes. It aims to ensure that water resources of the Murray-Darling Basin and ensure integrated and sustainable management. This Act established the Murray-Darling Basin Authority (MDBA) to oversee water planning across the Basin, rather than previously under the Murray-Darling Basin Commission with each state represented. It also aims to establish limits on sustainable water extractions (establishing sustainable diversion limits) and requires the MDBA to prepare a strategic plan for the integrated and sustainable management of MDBA water resources (the Murray-Darling Basin Plan). This requires States to prepare environmental watering plans, guided by the Environmental Watering Plan under the proposed Basin Plan (MDBA, 2011). State water sharing plans need to be compliant with the Murray-Basin Plan by 2019. In addition, the *Water Act 2007* aims to give effect to relevant international agreements (including the Ramsar Convention, migratory bird treaties, and the Convention on Biological Diversity) and to provide for special measures, in accordance with those agreements, to address the threats to Basin water resources.

Commonwealth Environmental Water Holder

To support the actions of the MDBA, the Water Act 2007 also establishes the Commonwealth Environmental Water Holder to acquire and manage the environmental water rights to water in the MDB, in accordance with the Environmental Watering Plan described in the *Murray-Darling Basin Plan*. The Commonwealth Environmental Water Holder acquires water entitlements with the objective of returning more water to the environment. The Commonwealth Environmental Water Office (CEWO) aims to support adaptive management and improvement in the management of Commonwealth environmental water to meet ecological objectives, including identification of information knowledge gaps. To this end, it has developed a Monitoring, Evaluation, Reporting, and Improvement (MERI) Framework, which integrates adaptive management concepts such as planning through program logic, an iterative cycle which allows both reflection on what is working and what is not working as well as changes to program direction or arrangements based on this reflection. The improvement process for use of Commonwealth environmental water will be based on evaluation of ecological outcomes from the use of water and the watering actions undertaken. It includes mechanisms for incorporating learning and new knowledge into planning, management, and decision making as well as a selection of management activities, specifically designed to test hypotheses through ecosystem-scale experiments (CEWO, 2012a). As of 31 January 2013, the Commonwealth environmental water holdings for the entire Murray-Darling Basin totaled 1,521,209 ML of registered entitlements (CEWO, 2013a). This includes water purchased from willing irrigators. In July 2011-June 2012, 40 gigalitres of Commonwealth Environmental Water were delivered to the Macquarie Marshes (CEWO, 2012b).

The ***Murray-Darling Basin Plan 2012*** aims specifically to provide enough environmental water to sustain ecological resilience during dry periods, enough flow to keep the Murray mouth open to the sea in most years and adequate water quality to sustain key human uses. The main mechanism of the plan is to set environmentally sustainable limits on the amount of water that can be taken from the Basin's water resources (including both surface and groundwater), known as Sustainable Diversion Limits (SDLs (MDBA, 2011). The Environmental Watering Plan under the MDBA proposed plan provides the justification for why water is needed for the environment with the new diversion limits, including environmental targets. In addition, the draft Murray-Darling Basin Plan requires each state to develop catchment-level environmental watering plans that align with the proposed Basin plan. These will be the water sharing plans currently in place for most catchments in the States.

The Murray-Darling Basin Plan integrates adaptive management principles as well as provisions for climate change adaptation (MDBA, 2011). A central part of its implementation is a monitoring and evaluation program for learning from experience, reported annually. Future scientific and socioeconomic research will focus on linkages between environmental watering, environmental outcomes, and social and economic consequences, economic research into the value of ecosystem services, and improved modelling of costs and benefits. In addition, the plan aims to integrate local organisations into the adaptive management of Basin water resources to make use of local knowledge and solutions and build capacity for communities, states, and Commonwealth to work together (Table 25).

The *Water Act 2007* includes some consideration of climate change adaptation, such as identification of climate change as a risk to Basin water resources, and provides strategies to manage those risks, although there are no clear adjustments. It also applies adaptive management principles to Murray Increased Flows. The Basin Plan considers risks from climate change, aiming to improve knowledge on the impact of climate change on environmental watering requirements, and ensuring that water-dependent ecosystems are resilient to climate change and variability, including extreme weather events. The proposed Basin Plan states that reduction in consumptive diversions will buffer the impacts to the environment until more is known about the implications of climate change. The median projected impact of climate change is within the range of water availability being considered in the Basin Plan (MDBA, 2011).

About ten per cent of the Macquarie Marshes are part of a designated Nature Reserve and subject to the provisions of the NSW ***National Parks and Wildlife Act 1974*** as a protected area. This Act relates to national parks, historic sites, and other protected areas and aims to preserve and manage these areas and conservation of nature through ESD principles. It establishes the institutional framework for the management of protected areas. The primary management mechanism is the development of statutory management plans for each protected area based on biodiversity conservation, wilderness values, rehabilitation and maintenance of natural processes, protection of landscape values, and fire management, as well as the encouragement of appropriate research into natural and cultural features and processes including threatening processes. These management plans are meant to be reviewed and revised every 10 years, based on appropriate research and monitoring. The Macquarie Marshes Nature Reserve Plan of Management was completed in 1993 but has yet to be reviewed (Table 25). The conservation objectives of this plan, including maintenance of the reserve as a healthy and diverse wetland habitat for all native wildlife and all types of native vegetation, have not been met, due to factors beyond the control of the conservation agency. The review of this plan has been flagged as a management response in the Macquarie Marshes Adaptive Environmental Management Plan and is underway (NSW, 2010b). In addition, the NSW National Parks and Wildlife Act 1974 requires that the conservation agency protect native fauna and flora throughout the Macquarie Marshes. This is carried out through broad consideration of the entire ecosystem in management of water and invasive species. It is also particularly important in the management of breeding colonies of waterbirds, many of which reside outside the boundaries of the reserve.

The ***Threatened Species Conservation Act 1995*** works through listing for protection of threatened species, populations, ecological communities, and key threatening processes by an independent Scientific Committee, as well as identifying critical habitat. The Act also provides for drafting and implementing recovery plans for threatened species, populations, and ecological communities and threat abatement plans to manage key threatening processes (Table 25). Recent amendments to the Act also provide for Biobanking agreements/trading in biodiversity credits.

There are 34 species listed as endangered or vulnerable in NSW recorded from the Macquarie Marshes (Appendix A). Also listed under the TSC Act is the endangered ecological community of coolibah-black box woodlands of the Darling Riverine Plains. In addition, the marshes are impacted by the listed key threatening process of Alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands.

The NSW Office of Environment and Heritage lists actions to deal with alteration of flows, including improved and continuing research and modelling, education and community awareness campaigns, reviewing current policy for flow-modifying structures, identifying rivers and wetlands of high conservation value and biodiversity, and determining impacts of altered flow regimes on biodiversity. However, while these actions will go some of the way towards abating this key threatening process, they do not specifically address the underlying cause, which is the regulation of river flows and subsequent diversion for human use. The Macquarie Marshes ecosystems are highly dependent on how their flow regime, regulated by other agencies at the State and Commonwealth levels. The increased environmental flows to the Macquarie Marshes through the State and Commonwealth buybacks of water certainly address this key threatening process. Activities aimed at conserving threatened species or ecosystems under this framework must be integrated with policies for returning environmental water to the marshes (e.g. Riverbank, Commonwealth Environmental Water) to be effective.

The ***Fisheries Management Act 1994*** aims 'to conserve, develop and share the fishery resources of the State for the benefit of present and future generations by conserving fish stocks and key fish habitats, conserving threatened species, populations, and ecological communities of fish and marine vegetation, and promoting ecologically sustainable development. Under this act, the aquatic ecological community of the Macquarie Marshes as part of the natural drainage system of the lowland catchment of the Darling River is listed as an endangered ecological community, and the silver perch is listed as a vulnerable species (Department of Environment Climate Change and Water NSW, 2010a).

The ***Water Management Act 2000*** was part of a broad reform of the NSW water sector to provide for the protection, conservation and ecologically sustainable development of the water sources of the State, and for other purposes. The *Water Management Act 2000* mandated the development of a State Water Management Outcomes Plan which was an overarching plan for the state's water resources that classifies categories of water sources (e.g. environmental water, licensed environmental water, adaptive environmental water), and management plans for water sharing, water protection, water source protection, floodplain management, and drainage management. The State Water Management Outcomes Plan ceased in 2007 but many of the principles and targets remained relevant. As of 2011, over 95 per cent of the water extracted in NSW was covered by the Act (NOW, 2011).

Under this legislation, the water sharing plans relevant to the Macquarie Marshes are the Water Sharing Plan for the Macquarie-and Cudgegong Regulated Rivers Water Source 2004 and the Water Sharing Plan for the Macquarie Bogan Unregulated and Alluvial Water Sources 2012. These plans establish water sharing rules for these sources including determining how the water available for extraction is to be shared, as well as establishing provisions for water licences, accounting and water trading, the extraction of water, the operation of dams, and the management of water flows (DIPNR, 2004). The unregulated water-sharing plan governs management of flows upstream in the catchment by setting long-term annual extraction limits for the combined water access licence holders annual access to water for both unregulated surface water and alluvial groundwater sources. It also defines daily access rules that govern when licence holders are permitted to extract water. These rules, known commonly as cease to pump (CtP) rules, provide protection for fish and other aquatic species during dry times (NOW, 2011). These plans will need to be compliant with the overarching Murray-Darling Basin Plan by 2019.

The *Water Act 2000* stipulates that water-sharing plans must recognise the effect of climatic variability on the availability of water. However, it does not specify climate adaptation provisions, such as adjusting the amounts of allocations in response to climate change. The Act does state that the principles of adaptive management should be applied, by making water plans responsive to monitoring and improvements in understanding of ecological water requirements. Water management plans are valid for 10 years but subject to audit or review every five years, based on more accurate scientific knowledge (e.g. to provide additional water to the environment due to findings that the previous amount was inadequate for healthy ecosystem functioning). This does not provide for explicit identification of objectives. The *Water Management Act 2000* requires the Natural Resources Commission (NRC) to formally review water sharing plans before a decision is made on whether they should be extended beyond their initial 10-year term. The NRC is an independent body established to provide independent advice to the NSW Government on natural resource management: what is working, what needs fixing, and how it is tracking against its stated policies and targets.

The Water Management Act 2000 lists the **State Water Corporation** as a major utility. This utility is New South Wales' rural bulk water delivery business and it performs the actual management of flows and delivery of water. State Water owns, manages and operates bulk water infrastructure to deliver water to approximately 6,300 licenced water users on regulated rivers as well as environmental flows. State Water operates in accordance with NSW water sharing plans which determine the rules for sharing water resources in regulated rivers between consumptive users and the environment. In the Macquarie River, State Water is responsible for delivery of water for licence holders from the regulated supply as well as declaring periods when supplementary water may be accessed.

The ***Catchment Management Authorities Act 2003*** established catchment management authorities in NSW, devolved some natural resource management functions to them. The goals of the legislation are achieved by developing catchment action plans, financially supporting catchment activities and assisting landholders to further catchment action plan goals. There is also a focus on providing education and training for natural resource management. Catchment management plans are periodically reviewed, at least every five years by the Natural Resources Commission.

The Macquarie-Castlereagh Catchment and the Macquarie Marshes fall under the Central West Catchment Action Plan 2011-2021. This focuses on resilience thinking and incorporates many aspects of adaptive management. These include a comprehensive Monitoring, Evaluation, Reporting, and Improvement program to provide the necessary information needed for flexible management. The CAP also incorporates the adaptive management tools of thresholds of potential concern, state and transition models, and organised program logics (action, management targets, and catchment goals. The CAP acknowledges that a systems understanding of the socio-ecological system is required to determine appropriate investment and activities by the CMA.

Riverbank

In 2005, the NSW Government established Riverbank, a mechanism designed to purchase irrigated water, to restore the ecological health of rivers. It built on the principles of the Water Management Act 2000 and the 2004 National Water Initiative agreement to establish ‘clear pathways to return all systems to environmentally sustainable levels of extraction’, and in support of the Australian Government’s Ramsar commitments. It was a $105-million environmental fund to buy water for the state’s most stressed and valued inland rivers and wetlands. RiverBank is administered by the Office of Environment and Heritage (OEH) with funding through the NSW Environmental Trust, using funds from a waste levy. RiverBank worked within the existing water market, purchasing only from willing sellers. As a legitimate market participant it aimed to support water-dependent ecological assets on both public and private lands, and provide a price signal in the market that reflected ecological values. In the Macquarie Valley, RiverBank water targeted vegetation communities in the north marsh Nature Reserve, the private Ramsar site, and small wetlands on the Macquarie River upstream of the Macquarie Marshes (DECCW, 2010c). This water is generally now managed with the entire portfolio of environmental water for the Macquarie Marshes.

Environmental flow management

The Macquarie Marshes currently has about 312,700 ML of environmental water consisting of a wildlife allocation (160,000 ML), Riverbank water (52,850 ML) (OEH, 2013b) and Commonwealth Environmental Water (99,892 ML as of January 2013) (CEWO, 2013b) . Management of this environmental water is primarily by the environmental flow manager within the NSW Office of Environment and Heritage. An MOU between the NSW government and the Commonwealth Environmental Water Holder provides guidelines for the effective use of all environmental water held by the two organisations. In addition, the water manager is assisted by an Environmental Flows Reference Group (EFRG), consisting of government agencies and non-government stakeholders (irrigation, grazing, environment) (Fazey et al., 2005). This is the critical advisory group for making decisions about environmental flows. The water manager provides the advisory group with a range of different options, depending on the availability of environmental water and the condition of key assets within the Macquarie Marshes.

Healthy floodplains project

In 2012, the NSW Government received a $50 million grant to initiate the Healthy floodplains project, which aims to reform the management of water on floodplains through the development of valley wide floodplain management plans and licensing of floodplain extractions, as well as to improve watering of key environmental assets across New South Wales. The project is to be implemented over a five-year period in five northern valleys including the Macquarie Valley(NOW, 2012). In addition to management planning, the project will increase the volume of flow to wetlands on floodplains through controls on water capture and modification of works. Other aims include improved understanding of the relationship between floodplain flows, extractions, and wetland health in order to improve floodplain water management, improved water accounting accuracy to improve certainty about compliance with long term extraction limits and future sustainable diversion limits (under the Basin Plan), and to ensure that environmental water entitlements held by environmental water managers (eg. Riverbank) can be used to support flood-dependent ecosystems. According to the project timeline, the scoping study for the Valley Wide Floodplain Management Plan for the Macquarie Valley is due to be completed by September 2013, with the complete draft plan due by September 2014 (DSEWPC, 2012).

Role of Local Government

Local government authorities play an important role in strategic planning, development control, and environmental reporting within their council or shire area. Their designated functions are specified in the NSW *Environmental Planning and Assessment Act 1979* and the *Local Government Act 1993*. Local councils designate land use zones and permitted types of development according to local environment plans (LEPs), which set out the regulations and provisions for each type of development. Certain developments require the consent of the council, and a development application with a 'statement of environmental effects' must be lodged. Other developments with a high potential for adverse impacts due to scale, nature, or location near sensitive environmental areas must lodge an environmental impact statement (EIS) and advertised to the public. Objectors to the proposal have merit appeal rights to the Land and Environment Court. In addition, councils can develop Development Control Plans (DCPs) that set out a consent authority's expectations for local government areas and must be take into consideration in the development assessment process, although they are not legally binding 'environmental planning instruments' such as LEPs. A 2012 reform diminished the role of DCPs so that they will not be 'preventing' or 'unreasonably restricting' development that is otherwise permissible under any environmental planning instrument (Parrino and Morphett, 2012).

The NSW Government has recently proposed new, sweeping reforms to the NSW planning system that aim to make the system 'simple, certain, transparent, efficient, effective, integrated, and responsive'. These reforms, laid out in a green paper, A New Planning System for NSW Green Paper introduce subregional delivery plans for growth areas, and introduce local land use plans which would replace local environmental plans (LEPs) and development control plans (DCPs). The plans will have four parts: Part A – a clear, simple explanation of what the plan is trying to do; Part B – a spatial land use plan, which will zone land in accordance with a 'more flexible' standard instrument (a template for councils to base their planning around); Part C – an outline of local, regional, and state infrastructure to be provided to support development; and Part D – development guidelines and performance measures. For the zoning framework, the green paper proposes three new zones to bring greater flexibility by allowing a larger number of compatible land uses in a particular area: the 'enterprise zone' (employment-related development but also mixed use housing investment), the 'suburban character zone' (low-density residential), and the 'future urban release area zone' (formally designating land for future greenfield development). The green paper also states that under the new system, "guidelines should facilitate outcomes desireable to the market, not dictate solutions that preclude choice and flexibility" (Gadiel et al., 2012).

The marshes lie within the Warren Shire local government area, and are thus covered under the Warren Shire LEP 2012. The LEP designates the entire area of the Ramsar-designated wetland as an 'environmentally sensitive area' which, is excluded from any exempt or complying development according to the LEP. This also includes a 100-metre buffer zone around the wetland (NSW Government, 2012). However, since the Macquarie Marshes depend on inflows from the rivers and floodplains in the surrounding region, any development that may impact these incoming watercourses could also impact the marshes ecosystem, including agricultural developments, water infrastructures, or other land uses. Considering that private land surrounds the marshes, the provisions of the LEP could be highly relevant to ensuring sustainable land management in line with conservation goals for the wetlands.

Under section 428 of the *Local Government Act 1993,* local governments are also responsible for local and regional State of the Environment (SOE) Reporting. A local SOE provides a summary of the attributes of the local government environment and human impacts on the environment. In addition, it lists the activities of the government (all levels), industry, and community in protecting and restoring the environment. Local SOES also provide regularly updated, scientifically sound information for the public, government, and other decision makers as well as reporting on the effectiveness of environmental programs and policies. They can provide input into policy development by integrating environmental information with social and economic information and identify current and emerging issues and important gaps in knowledge and data collection. Local governments must include SOE reporting in their annual reports, as well as comprehensive SOE reports every four years. The reports must address the following environmental sectors: land, air, water, biodiversity, waste, noise, aboriginal heritage, non-aboriginal heritage, and make particular reference to environmental management plans, special council plans relating to the environment, and the environmental impacts of council activities (Dubbo City Council, 2012).

The most recent SOE report relevant to the Macquarie Marshes is the 2011-2012 Comprehensive State of the Environment report for the Councils of the Greater Central West Region of NSW: Bathurst, Blayney, Bogan, Bourke, Cabonne, Coonamble, Cowra, Dubbo, Gilgandra, Lachlan, Mid-Western, Narromine, Oberon, Orange, Warren, Warrumbungle, and Wellington. The report was funded by the Central West Catchment Management Authority with contributions from the 17 participating local councils. As a comprehensive report it shows trends, where possible, in relation to the last Comprehensive regional report produced in 2008-09 and subsequent supplementary reports from 2009-10 and 2010-11. The report follows a threat-response format covering each of the environmental sectors and provides indicators for each.

3.4.5. The Challenge – sustainable management of the Macquarie Marshes

There are clearly many different legislative and policy commitments which interact and potentially confound good integrated management of the Macquarie Marshes. In addition, there are operating mechanisms which are critical to the management of environmental water but may not be widely known (e.g. rules for the release of environmental water). Jurisdictions and agencies need to deal with multiple cross-cutting issues (threatened species, environmental water requirements/allocations, integrated catchment management, wetlands protection, land management). This multi-layered policy landscape is not well-integrated or coherent and thus it is difficult to navigate and achieve stated conservation goals (Table 25). There is opportunity to retreat to particular legislative or policy positions, rather than consider the long-term ecological health of the ecosystem, within the constraints of current water sharing. Integrated natural resource management represents a major challenge for implementation because of the often wicked nature of problems and the different responsibilities and agencies charged with implementation. Sustainable management of the Macquarie Marshes, a large socio-ecological system, epitomises such a challenge. Despite this, much of the current operating practice of management lends itself well to a rigorous framework of Strategic Adaptive Management (Kingsford et al. 2011; Kingsford and Biggs 2012). This could potentially coordinate and better integrate roles and responsibilities to improve the management of the Macquarie Marshes.

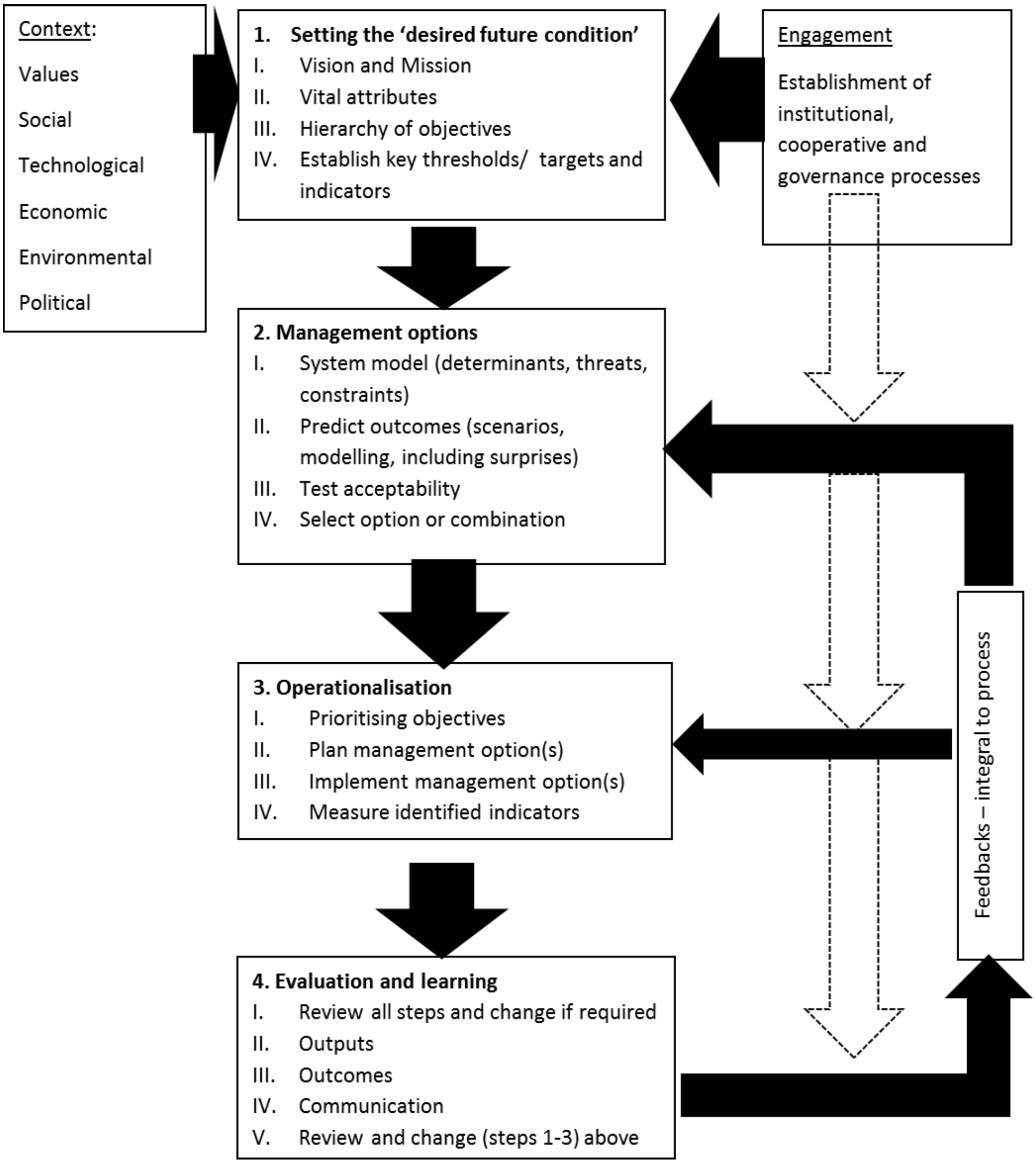
The marshes are part of a complex socio-ecological system with multiple competing interests and stakeholders and dynamic ecological needs. SAM provides an integrated, rigorous framework for biodiversity conservation. SAM is based on a series of four steps that could form a plan for management of the Macquarie Marshes as a socio-ecological system. These steps are: setting the 'desired future condition'; identifying management options; operationalising these (doing the management), followed by evaluation and learning (Kingsford and Biggs, 2012b). As adaptive management is a cyclical, iterative process, the final step of evaluation and learning should generate questions for the previous three steps in a feedback process. This provides for ongoing learning that allows for adjustments to models, goals, and management practices (Kingsford and Biggs, 2012b).

Given the different legislative responsibilities, it is important to show how responsibilities and current practices of different agencies, supported by their legislation, can integrate into such a framework. Water and land management are inextricably linked and critical to successful sustainable management of a wetland of international importance such as the Macquarie Marshes. If these are well integrated and focused on clear conservation goals articulated by different policies and legislation, then natural processes should support resilience of an ecosystem, including its functions and dependent organisms. This provides the logic for an approach at integration: 1) flow regime, 2) relevant land management and 3) the ecosystem and its dependent functions and organisms.

Application of SAM framework to the Macquarie Marshes

Good progress has occurred in the implementation of the SAM approach to the management of the Macquarie Marshes Nature Reserve (Kingsford et al. 2011; Kingsford and Biggs 2012), including partial development of a SAM plan for the Nature Reserve (OEH 2012). While focusing only on the Nature Reserve, this approach is much more widely applicable to the entire wetland, including environmental flow management and floodplain management. It is within this context that we show how different legislative and policy frameworks can be coordinated and integrated to provide a cohesive and coherent approach to managing the entire wetland system. To do this, we follow the framework and its current stage of development but applied to the entire Macquarie Marshes, including additional development in relation to environmental flow management, floodplain development and management of areas not currently part of the public estate (i.e. much of the Macquarie Marshes is not owned by the government). This first involves a discussion about the overarching processes: context and engagement. This is followed by the four steps of the framework and finally implementation of learning cycles and documentation (Figure 45). The SAM approach should be captured in a document – the Strategic Adaptive Management Plan for the Macquarie Marshes. This can be used as a planning and accountable document which at different levels records current progress. Finally, we discuss the format of this document and key accountability for implementation.

Figure 45: Strategic Adaptive Management Framework (SAM) with its four main steps (adapted from Kingsford and Biggs 2012).



The SAM framework

Overarching processes

a. Context

This section focuses on social, technological, environmental and ecological, economic and political values. It sets the critical background for defining the desired state and what can be achieved. Many of these values are well established and identified for the Macquarie Marshes and form the beginning of government documents (OEH 2012; MDBA environmental watering; Macquarie Marshes Plan of Management; Ecological Character description). In particular, this section needs to articulate the social (cultural) values, technological capacity, environmental and ecological values, economic values and political and legal issues. These need to encompass the full extent of the Macquarie Marshes, including private landholdings reliant on flooding. Many of the areas have critical values of importance for the Macquarie Marshes as a whole and recognised by governments in their management, although not always articulated.

- *Social values* include identifying areas of cultural significance but also include the importance of underlying values required for managing such a complex ecosystem, including custodianship, sustainability, resilience and intergenerational equity (Kingsford and Biggs 2012). This would also include a commitment to Strategic Adaptive Management which is articulated in much of the legislation and policy for the Macquarie Marshes (see sections above).
- *Technological capacity* includes current tools that can assist with management, access to data and predictive models of changes to the system as a result of management.
- *Environmental and ecological values* focus on the species and ecosystems that are identified as important in different legislative frameworks (e.g. Ramsar, threatened species). They also incorporate the functional importance of different parts of the wetland and key aspects that are acknowledged of value (e.g. colonial waterbird breeding, reedbed swamps, river redgum forests). This context also needs to incorporate current understanding of the condition of the Macquarie Marshes.
- *Economic values* include the clear economic values of the wetlands (i.e. floodplain grazing, outside the Nature Reserve), tourism and non-use economic value. They should also articulate ecosystem services provided by the wetlands.
- *Political and legal obligations and constraints* encompass commitment by governments and communities to the Macquarie Marshes. Much of this information is captured in current legislative and policy frameworks (e.g. Ramsar-listing; Environmental Watering Plan of the Murray-Darling Basin Authority; Water Sharing Plan) but needs to be articulated within the context, providing a ready reference and guidance to objective setting. This section would outline the environmental flow management obligations and arrangements of different parties, including the volume of water available. It would also list other potential constraints on achieving potential rehabilitation goals (e.g. infrastructure in channel and floodplains).

b. Engagement

There are well established processes and mechanisms for engagement in the Macquarie Marshes and its management, including the Environmental Flows Reference Group, National Parks Advisory Committee, Catchment Management processes. Ideally, these could be consolidated into one committee which focuses on the entire Macquarie Marshes and its management. This may require increased representation from landholders in the Macquarie Marshes. The obvious mechanism to provide this engagement could be the Environmental Flows Reference group but with expanded terms of reference to focus on other issues not necessarily related to environmental flows, including floodplain development and invasive species. This stakeholder group would also necessarily require membership from all relevant state government agencies at State and Federal levels involved in the decision-making for the Macquarie Marshes.

Setting the 'desired future condition'

The next stage of implementation of a SAM framework is to clearly define the desired future state, through a series of steps (Figure 45). These steps are iterative, constantly informing, updating and testing the rigour of previous steps. The establishment of a vision and mission needs to be constantly informed through the development of the hierarchy of objectives. Considerable progress has occurred in development of the desired future state for the Macquarie Marshes Nature Reserve (OEH 2010) and much of this is repeated here as it is equally applicable to the entire Macquarie Marshes. Where there is a need for extension, we have identified these areas.

- *Vision and Mission*. The vision is usually an articulation of what the desired future condition will be in 20-50 years while the mission deals with how to achieve this vision. The Macquarie Nature Reserve has a vision and mission (OEH unpubl. 2010). The vision is: "The Macquarie Marshes is a place where frequent floods support abundant and diverse wildlife and communities". This recognises the ecological and social dimensions. The mission is "To restore the Macquarie Marshes so that it has its full functional complexity and ecology (native species, communities and processes), built around productive partnerships", encapsulating how this could be adequately achieved. This vision and mission could easily be migrated to an overarching SAM framework for the entire Macquarie Marshes, allowing for different stakeholders (private and public) to become engaged in the entire management of the Macquarie Marshes.
- *Vital or key attributes.* This should represent the principal essence of the ecosystem. Ideally these should capture the main elements of the system from the biophysical, cultural and other values. There should be about 5-15 attributes with sufficient focus to provide good direction for management (Kingsford and Biggs 2012). Currently, eight key attributes (called values) have been identified for the Macquarie Marshes Nature Reserve (OEH 2012): four vegetation communities (river red gum forests, common reeds, water couch and coolibah/ blackbox woodlands), open lagoons, waterbird breeding, aboriginal cultural heritage and partnerships (landholders, government, scientists). These are collapsed into three key values – waterbird breeding, vegetation communities and culture and heritage. This suite could equally apply across the Macquarie Marshes, including private landholders. It is likely that there would also be a key value related to communities within the Marshes also included.
- *Hierarchy of objectives*. This is guided by vision, mission and key attributes. An extensive hierarchy of objectives is already developed for the Macquarie Marshes Nature Reserve (OEH 2012, Appendix x), providing considerable guidance to how this could be developed more broadly for the entire Macquarie Marshes and also for other management targets. For extension to the entire Macquarie Marshes, there would likely be low level objectives related to provision of sufficient flows for supporting livestock grazing outside the Macquarie Marshes. In addition to high level objectives (Appendix), there are clear fine scale objectives that relate to flow and inundation: surface water, groundwater and groundwater/ surface water interaction.

- *Indicators, targets and thresholds*. The objectives hierarchy leads directly to a suite of different indicators (e.g. soil moisture, inundation mapping, river red gum condition, waterbird breeding). There are clear principles that should be considered in identification and resourcing for collection of data on indicators (Kingsford and Biggs 2012). These include making sure that indicators relate to the key attributes; indicators need to be sensitive to change; data needs to be collected on likely determinants of indicators and; there should be a focus on key aquatic biota, not just surrogated (e.g. hydrology). Not all indicators can measured given limited resources but these provide a potential list of priority indicators. Targets and thresholds are primarily established in relation to understanding of the variability of each of the indicators. If there is data available, then thresholds can be established. In some parts of the Macquarie Marshes, there are clear thresholds that have been exceeded (i.e. dead river red gum). It would be possible to develop thresholds for much of the vegetation community and breeding of colonial waterbirds. The objectives hierarchy also provides an opportunity for the managers to signal to partners (e.g. scientific researchers) the clear priorities for measurement.

Management options

- There is considerable interaction between setting the desired future condition and the management options. Specification and identification of management options is dependent on good understanding of the system and its likely responses. Clearly, this understanding will grow over time with good information.
- *System model (determinants, threats, constraints)*. The system model, sometime termed a 'process' model attempts to capture current understanding of how the system works. It is important to identify the major drivers that underpin cause and effect which can be captured in a simple cause and effect diagram (Kingsford and Biggs 2012). This can clarify to stakeholders how the system works. It can include understanding of the impacts of river regulation, fire, grazing and climate change. Critically, such a process model then promotes quantification and development of appropriate models which reflect these processes and build the capacity for improved predictions and scenarios.
- *Prediction of management options (scenarios, modelling).* Managers routinely need to make decisions about their options and do so skilfully, supported by whatever tools are available. With increased knowledge and sophistication, it should be possible to increasingly utilise the useful scientific tools available to predict outcomes. These will inevitably be largely dependent on the sophistication of the models that underpin they system and can range from simple models to highly sophisticated models which compare many different biotic responses. Ideally, these can also be placed into an easy to use display (see data information platform) so that the stakeholder group can easily communicate the outcomes. From a suite of potential management options, a few candidate options are likely to emerge that are plausible options for management.
- *Test acceptability*. With the candidate management options, managers can then test their acceptability with stakeholders to determine the best option to pursue. Some testing may be required to determine how management options relate to objectives and the vision and ensure that there is good agreement. An inevitable and extremely difficult dimension in testing acceptability is to identify the tradeoffs between meeting short-term objectives at the costs of long-term objectives that may be more important. The challenge for science is to provide the requisite tools to inform this decision-making. It should be possible over

time to model potential responses of indicators which can then form the basis for testing with the management.
- *Select option or combination*. The selected option(s) (there may be more than one in an experimental context) may require testing whether there are sufficient resources to collect data on key indicators. It may be necessary with sufficient resources to collect specific data related to the management action.

Operationalisation

The next major step is to implement the management option(s) (Figure 45). This requires some explicit steps.

- *Prioritisation of objectives*. It is useful to review the bottom level of the hierarchy of objectives which should be the reason for the management action and identify which of these objectives is to be met by the management. More often than not, there will be a wide range of different objectives exercising pressure on resources. It is useful to adopt a risk assessment approach which allows testing among a range of disparate objectives to determine which are likely to deliver the required outcomes for the system (Kingsford and Biggs 2012). Some objectives may relate only peripherally to a particular management action. For example the management of feral animals may not be clearly tied to the management of environmental flows. The former may require a different unrelated management action (i.e. shooting).
- *Plan management option.* This step is well defined by managers and requires identification of resources and the timing of the management action. It is also important to identify data collection requirements for indicators which includes the collection of data before the management action so that responses of the ecosystem can be adequately measured and reported.
- *Implement management option.* This step is simply ensuring the alignment of the actual management option with delivery with sufficient resources.
- *Measurement of identified indicators.* With the management action, data needs to be collected for identified indicators to measure the responses of the ecosystems. These need to align with potential thresholds identified to determine if defined thresholds are exceeded, requiring further management. Indicators can be reported on short and long-term scales. In the short-term managers can be provided with rapid data but this will not be adequately interpreted. Long-term interpreted data will allow for investigation of cause and effect and likely relationships, particularly the role of different lags in responses of organisms and processes.

Evaluation and learning

This final step closes the loop in learning, allowing for an assessment of whether objectives were achieved by the management action, the uncertainty in predictions from models, updating of models with new insights and data and storage and display of the data.

- *Review all steps and change*. There are a series of explicit questions which can be asked of the management action, relating to the realisation of predictions in the ecosystem response. These questions should relate from the particular to the general (Kingsford and Biggs 2012). Particular questions relate to whether the management action was realised; were the outcomes acceptable; was the monitoring adequate; were the objectives achieved in relation to the vision and mission.
- *Outputs*. There should be various documents which report on the management. There may also be media, workshop and presentation outputs. These may all be summarised into one document.

- *Outcomes*. The most critical issue is whether environmental outcomes are met that relate to the overall vision and mission. This requires assessment of the management action in relation to the ecosystem and its response. This needs to be in the context of its desired ecological condition.

Integration of legislation, policy and processes into the SAM framework

There are a range of different responsibilities for policy and management of the Macquarie Marshes with different organisations. A SAM approach could unify and integrate these different responsibilities, to deliver on a common purpose. The major factor determining the ecological health of the Macquarie Marshes is the amount of environmental water flowing into the marshes, combined with the natural flow regime, determining how much and when this water is released. A SAM framework could help build on the established process, providing clear links between different aspects of environmental flow management including how this links with to terrestrial aspects of the Macquarie Marshes and its management. The following legislative or policy drivers are considered in relation to how they may integrate into a SAM framework.

NSW Office of Environment and Heritage

Two key functions operate within the NSW Office of Environment and Heritage relevant to the management of the Macquarie Marshes and potential implementation of a SAM framework: management of the Nature Reserve and Environmental flow management. These are already well integrated but a SAM framework could reinforce integration and ensure clear understanding of different responsibilities for management of this ecosystem.

Nature Reserve and responsibilities (National Parks Act)

A SAM framework already exists for the Macquarie Marshes Nature Reserve with most of the elements required (OEH 2012). This includes objectives that extend to the entire system which has long remained a key objective of the government. Specifically, there is a long history of practice for managing the Macquarie Marshes as a whole ecosystem, not just the Nature Reserve. A SAM framework for the entire system would assist, allowing managers of the Nature Reserve to specify specific objectives relevant to management of the areas of the Nature Reserve. A SAM framework could be the detailed framework which underwrites the Plan of Management.

Environmental flow management

A SAM framework could be used to build already established objectives for environmental flow management by the environmental flow manager and integrate these into the SAM framework established for the Macquarie Marshes Nature Reserve (OEH 2012). These already include objectives that extend to the entire system. It is possible to more explicitly develop fine scale objectives that will drive development and investment in appropriate indicators which can then be resourced appropriately ensuring that there is data relevant to the long-term management of the ecosystem.

Floodplain management

A SAM framework could be applied to the assessment and rehabilitation of floodplain areas affected by earthworks (Steinfeld and Kingsford 2012). In particular, this would rely on development of a series of objectives within the hierarchy which specifically addressed those structures considered critical to connectivity and ecosystem health. It could also assist in the development and identification of knowledge needs which would provide a target for the current health floodplains project.

New South Wales Office of Water

The NSW Office of Water is the primary agency responsible for the water sharing plan for the Macquarie River which provides water to the Macquarie Marshes. This requires regular review to test whether it is meeting its objectives. The SAM framework for the Macquarie Marshes could provide the suite of relevant objectives for which such a review would be integrated into the SAM process of evaluation and learning. As with other reporting processes, this would also reduce potential duplication in reporting as well as meeting the objectives of the water agency. Water sharing and management of the Macquarie River would need to be incorporated into the context as well as integrated throughout the SAM framework to ensure that management is bounded by reality. Similarly, the extraction limits and rules set by these plans can be integrated into the objectives and targets within an SAM framework.

In addition, there would be an opportunity to integrate responsibilities for land management relevant to connectivity and the floodplain. These could be integrated into the SAM framework with clearly articulated objectives for improving the desired ecological condition of the Macquarie Marshes.

NSW State Water

This agency is responsible for day to day management of the river. The rules and operations involved in delivering and deliberating on environmental flow management to the Macquarie Marshes could be incorporated into a SAM framework.

NSW Fisheries

This agency is responsible for management of fish populations in the Macquarie River and Macquarie Marshes. There are many clear relationships between the management of the river, the wetland ecosystem and fish populations, particularly in relation to connectivity. A SAM framework could have a series of objectives related to management of fish populations, including the impacts of barriers on communities.

Central West Catchment Management Authority

The Central West Catchment Management Authority has recently developed a Catchment Action Plan (CAP) based on resilience thinking and adaptive management principles including the development of catchment goals and management targets through program logic. Establishment of a SAM framework for the Macquarie Marshes would be consistent with this development. The aim is to build more resilient landscapes by ensuring that the relevant NRM plans or strategies are operating collaboratively and not in conflict. This harmonisation of strategies contributes to Step 1 of the SAM process by identifying common objectives. In the area of land management, including weirs on rivers, development on floodplains, and activities impacting water quality, the CAP is aligned with the NSW Diffuse Source Water Pollution Strategy, NSW Cold Water Pollution Strategy, NSW State Weirs Policy, NSW State Groundwater Framework Policy, NSW Groundwater Quality Protection Policy, NSW Salinity Strategy, the Macquarie Marshes Adaptive Environmental Plan, the Macquarie River Floodplain Management Plan (CWCMA, 2011b). The CAP also provides for state and transition models which are diagrammatic representations of how the socio-ecological system and how it responds to natural or management induced disturbances (Central West CWCMA, 2011a). The state and transition models include a model for water quantity, movement, and quality which incorporates the role of flow regimes on wetlands (Central West CWCMA, 2011a). This model provides an illustration of the relationships between river regulation and desired or undesirable states as well as the key drivers of these relationships. Such modelling is a useful tool for a SAM framework that can assist water managers and other stakeholders in understanding the socio-ecological system surrounding and including the Macquarie Marshes. This work combined with the current work already done for the Macquarie Marshes could assist in developing a system's models for the Macquarie Marshes which focuses not only on the environment but also the sociological aspects.

Commonwealth Government

There are three major functions within the Commonwealth Government, relevant to the management of the Macquarie Marshes: management of environmental water by the Environmental Water Holder, international responsibility for the Ramsar site and environmental watering plan and sustainable diversion limits overseen by the Murray-Darling Basin Authority.

Environmental Water Holder

The Environmental Water Holder holds a significant amount of environmental water (~100GL) is released as environmental flows through an agreement with the NSW Government. This primarily gives the NSW Government responsibility for active management, given the experience and relationships of individuals who manage environmental flows in the river. Commonwealth direction is provided by specific document relating to environmental outcomes for the Commonwealth Environmental Water Holder, as well as reporting on outcomes of management. A SAM framework could avoid any duplication in objectives among different organisations. It could also reduce reporting which is currently separate between the Commonwealth and State Governments. Most of all, a SAM framework could provide transparency to the wider community about the management of environmental flows in the Macquarie Marshes. The relevant elements of the current operating arrangements between the NSW and Australian government could be migrated into the SAM framework. This integration could also assist with clarity on investments in indicators which are currently primarily the responsibility of the NSW government. The Commonwealth Environmental Water Holder has decided not to invest resources in long-term monitoring in the Macquarie Marshes, despite the considerable amount of environmental flow held by the Commonwealth Environmental Water Holder, the well-established understanding and cooperation and responsibilities of the Commonwealth Government for the ecosystem as a Ramsar site for which there is already an admission of a change in ecological character.

Ramsar obligations

There is currently an admission of a change in ecological character to the Macquarie Marshes Ramsar site, requiring the Australian Government to address the effects of anthropogenic impact. The report on this process could show establishment of a SAM framework with increasing demonstration to the international community of the effectiveness of management and delivery towards outcomes leading to the desired ecological condition.

Murray-Darling Basin Authority (MDBA)

There are dual responsibilities for the MDBA following establishment of the Murray-Darling Basin Plan and the Sustainable Diversion Limits (SDLs): review of water sharing plan and guiding management through the Environmental Watering Plan. In addition, the MDBA has a strong commitment to adaptive management, including ensuring involvement of local stakeholders. These are all critical elements of a SAM framework. The SAM framework would also provide mechanisms for incorporation of the critical elements of the environmental watering plan including ensuring that the objectives are consistent throughout all organisations involved in the management of the Macquarie Marshes. The SAM framework would also establish the mechanism for reviewing effectiveness of the water sharing plan and sustainable diversion limits in meeting the desired ecological condition of the Macquarie Marshes.

3.4.6. Integration of climate change adaptation into the SAM framework

Loss of flooding due to river regulation is the key degrading factor in the declining resilience of the Macquarie Marshes wetland ecosystem, driving both ecological and social systems beyond viable thresholds, significantly increasing susceptibility to the impacts of climate change. Climate change and its adaptation will become increasingly important, given predictions of increasing aridity in the Macquarie Marshes. As summarised (see 3.2.3), climate change in the Macquarie Marshes will probably primarily drive reduction in flooding volumes and frequencies. The single primary adaptation for restoring the Macquarie Marshes ecosystem is the return of adequate environmental water needed to restore the short and moderate inter-flood intervals. This can be achieved through increased water entitlements for the environment or reductions in extractive share of flow through changes in legislation and policy. Presently, an explicit consideration of climate change adaptation strategies, within the developed objectives hierarchy, is lacking. Many of the objectives relevant for climate change adaptation remain relevant to climate change adaptation and have been practised in relation to impacts of water resource developments in the catchment. As a result, operating within a SAM framework, allows for establishment of objectives related to improving the condition of the ecosystem, mainly in the form of water management and obtaining adequate environmental water. Many of these objectives do not require additional modification except potentially adjustment of targets. One consideration may be to ensure refugia receive sufficient water and do not dry out even in extremely dry periods. Including climate change adaptation objectives (see 2.1.1) within an updated decision-making structure will help prioritise for key ecological assets as well as for choosing among alternative management strategies. True adaptation to climate change will require coordinated institutional and policy change which may be effected through the SAM approach. Critically, SAM depends on constraints and opportunities, which can be provided by legislation and policy as well as drivers in ecosystems.

3.4.7. Way forward

The most significant challenge for establishment of a SAM framework for the Macquarie Marshes is the willingness of different agencies to embark on this journey. It requires investment in joint development of a vision and hierarchy of objectives, which can drive management, monitoring and reporting. The current responsibilities of different agencies can be incorporated within a SAM framework but it does require a level of coordination, which would be challenging. This does not mean it would need to be established immediately. It could be treated as a journey. Many of the critical elements for a SAM framework and its implementation are already well established for the Macquarie Marshes.

3.4.8. Acknowledgements

We thank the range of people who contributed their experience and background to this report, particularly the Steering Committee (see 2.7) who provided valuable advice.

3.5. Adaptive Management Information Tool (AMIT)

3.5.1. Introduction

A critical constraint on management in general and devising adaptation strategies in particular is availability and access to scientific information. When available, high quality datasets can support decision-making and communication of relevant information to stakeholders. With better information and accessibility, better decisions can be made. Consolidating multiple datasets where data are accessible through a single point of entry carries several key advantages. A single dataset ensures data can be constantly updated and expanded to encompass all available data. Sharing of information is significantly more effectual in terms of resource use and can strengthen communication with the public on management outcomes. Importantly, key indicators can be jointly developed and used to provide a better understanding of response to environmental variation or managerial actions. These returns support better decision-making and guide future strategies of adaptation. Critical to adaptive management, robust data forms the basis on which management can evaluate its actions and form the basis for more efficient strategies required to achieve desired outcomes.

We developed a data platform that calls up data on biota, ecological processes, and modelling into a spatiotemporal interface. Use of data allows access to key scientific information and modelling for climate adaptation and management. This interface focuses on the response of flood dependant ecosystem processes to determine adaptation opportunities delivered with climate adaptation to altered flow regimes (e.g. environmental flow management) based on modelling approaches undertaken in this report and within the Australian Wetlands, Rivers, and Landscapes Centre.

Uniform resource locator (URL)

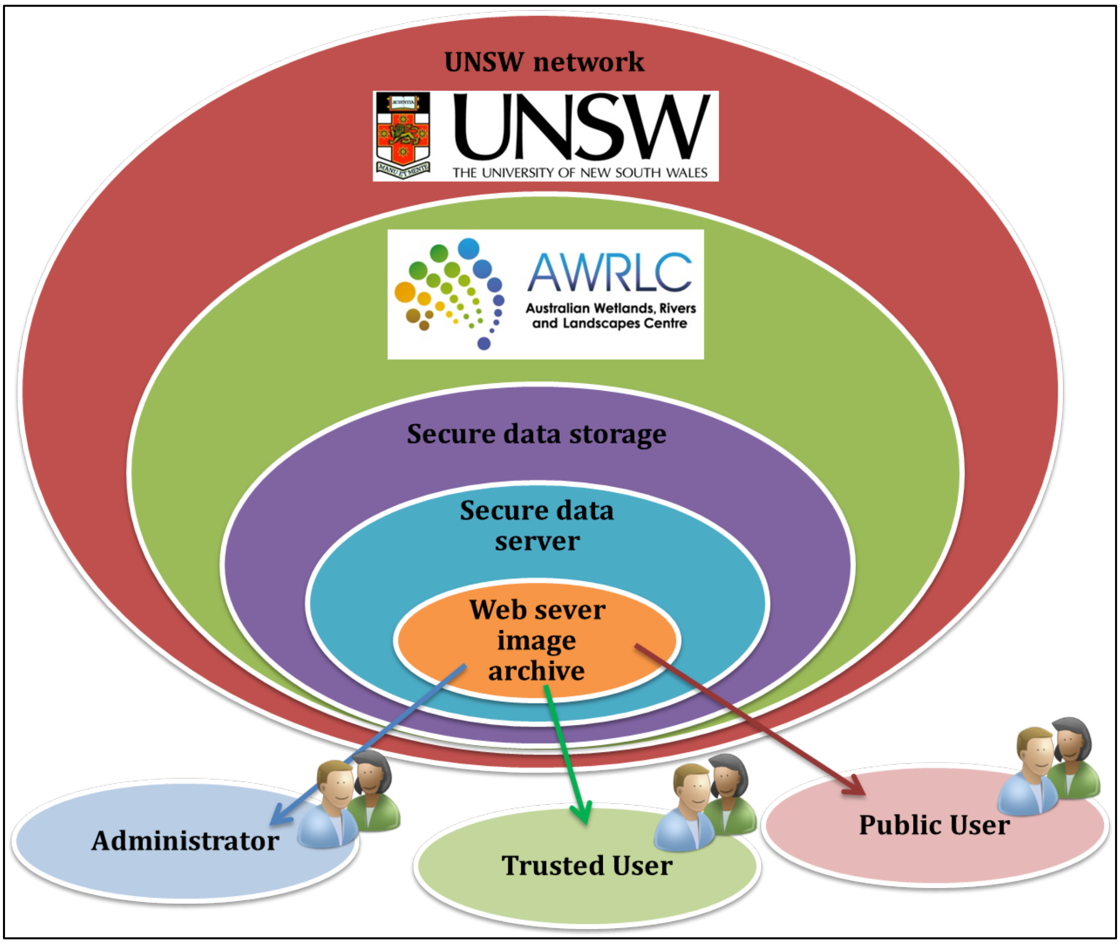
http://test.amitweb.science.unsw.edu.au/

3.5.2. Framework

The data platform aims to provide both a support tool for stakeholders as well as a portal for public access, where data security measures operated. Users are provided with varying levels of access to data as well as scale constraints. As the platform would be accessed through the internet, a dedicated test server has been configured for the task. A key requirement for the information platform was to provide spatial and temporal control to view and interact with the key data components identified for the project. Google Earth network links were identified as a suitable mechanism as they provided fast and efficient distribution of data while allowing a degree of security to the project's original datasets. Central to the useability aspect of the data platform is wide familiarity of users with Google Earth interface. This novel and interactive search framework using the Google Earth kml data structure allowed the efficient visualisation of point, polygon, and continuous field data and can represent complex information structures required for model outcomes, scientific reports and additional project information. We structured data layers into boundaries, drivers, and ecology, providing a useable representation of all the potential data sets (Table 28).

Access Framework

Figure 46: Access Framework of developed information platform and security organisation



3.5.3. IP and Licensing

Datasets comprise of biotic and environmental data collected from a wide range of sources including the AWRLC, OEH, as well as by a range of partners. While some datasets are a product of long-term collaborations with AWRLC which do not require licenses (e.g., Eastern Australian Waterbird Survey data and colonial waterbird data), others critical datasets required licensing agreements with our partners. Intellectual property and custodial issues have been formalised through an expanded use license agreement established with NSW Office of Environment and Heritage (OEH) specifically for set up of the data platform. To comply with OEH standards key licensing features have been maintained:

1. Set-up of data platform and data are part of a short-term project. However, once operational, the data platform will continue to operate through the AWRLC sever and will be updated regularly as new data becomes available.
2. Spatial extent of the data-platform and data will cover the Macquarie Marshes region (approximate boundaries: N6645742, W534630; S6494492, E582880).
3. Display of sensitive species will made in accordance to OEH Threatened Species Information Disclosure Policy whereby search for registered users returns coordinates for category 2 sensitive species denatured to 0.1 degree (~ 10km), and category 3 sensitive species denatured to 0.01 degree (~1km).
4. Request that platform will allow resolution display at finer than 1:250,000 for secured accessed users (e.g., OEH personnel). Users will be given a disclaimer that some layers cannot be considered accurate at finer scales.
5. General public will be restricted to a resolution of 1:250,000.
6. All displayed data will be referenced accordingly with due recognition of the Office of Environment and Heritage as the data source.

Collated Datasets

Table 28: Collated datasets, some of which were integrated into the data platform

Name	Group	Type
NSW Estate	NSW Estate	Boundary
Ramsar	RAMSAR	Boundary
Quambone	Aerial Images	Boundary
Walgett	Aerial Images	Boundary
RFS	Aerial Images	Boundary
Walgett & Wyngan	Aerial Images	Boundary
Landsat	Landsat	Boundary
LIDAR	LIDAR	Boundary
Flow volume	Hydrology	Driver
Inundation mapping	Hydrology	Driver
Fire history	Fire	Driver
Undefined in-stream structures	Structures	Driver
Channels	Structures	Driver
Levees	Structures	Driver
Off river storage	Structures	Driver
Tank	Structures	Driver
Uncertain earthworks	Structures	Driver
Rivers	Water bodies	Driver
Colonial Waterbird breeding	Birds	Ecology
Woodland Birds	Birds	Ecology
Aerial Survey of waterbirds	Birds	Ecology
NSW Atlas1	Fauna	Ecology
Historical fish data	Fish	Ecology
Invertebrate density	Invertebrate	Ecology
VegSurvey1949	Vegetation	Ecology
VegSurvey1963	Vegetation	Ecology
VegSurvey1981	Vegetation	Ecology
VegSurvey1991	Vegetation	Ecology
VegSurvey2008	Vegetation	Ecology
River Red Gums plots	Vegetation	Ecology
YETI	Vegetation	Ecology

3.5.4. Modelling framework for inundation in the Macquarie Marshes

Inundation of the Macquarie Marshes was classified from 95 flood maps (Landsat TM imagery) between 9/2/1989 to 21/1/2011 (unpubl. data R.F. Thomas, NSW Office of Environment, and Heritage). These flood maps were used to develop spatially explicit generalised linear models (GLM) of flood. These flood models were developed using recorded cumulative flow (Figure 47) and local rainfall (Figure 48) for the previous 30 days based on these 95 irregular flood dates. For every 25m x 25m land unit (Landsat pixel) in the water management area, the probability of the flooded presence is:

$$P(flooded) = exp(a_0 + a_1.fl + a_2.fl^2 + a_3.rn + a_4.rn^2)/(1 + exp(a_0 + a_1.fl + a_2.fl^2 + a_3.rn + a_4.rn^2))$$

Where fl denotes the total flow data at Marebone (Marebone Weir and Marebone Break), and rn is the cumulative rainfall data at Quambone stations for the previous 30 days. Coefficient values a_0, a_1, a_2, a_3 and a_4 were estimated for each study area land unit to produce spatially adaptive flooded probabilities for the Macquarie Marshes. These coefficient values are consequently used to produce spatially explicit predictive outcomes of inundation given input values of flow and rainfall. The range of these two variables is provided as a drop down options for choice. It is also possible to estimate likely flooding of the Macquarie Marshes using annual unregulated (assumes no dams or diversions) and regulated models based on the same range of options (see Ren, Kingsford and Thomas 2010 for details).

Figure 47: Cumulative flow (GL) for the previous 30 days, measured at Marebone Weir and Marebone Break, upstream of the Macquarie Marshes.

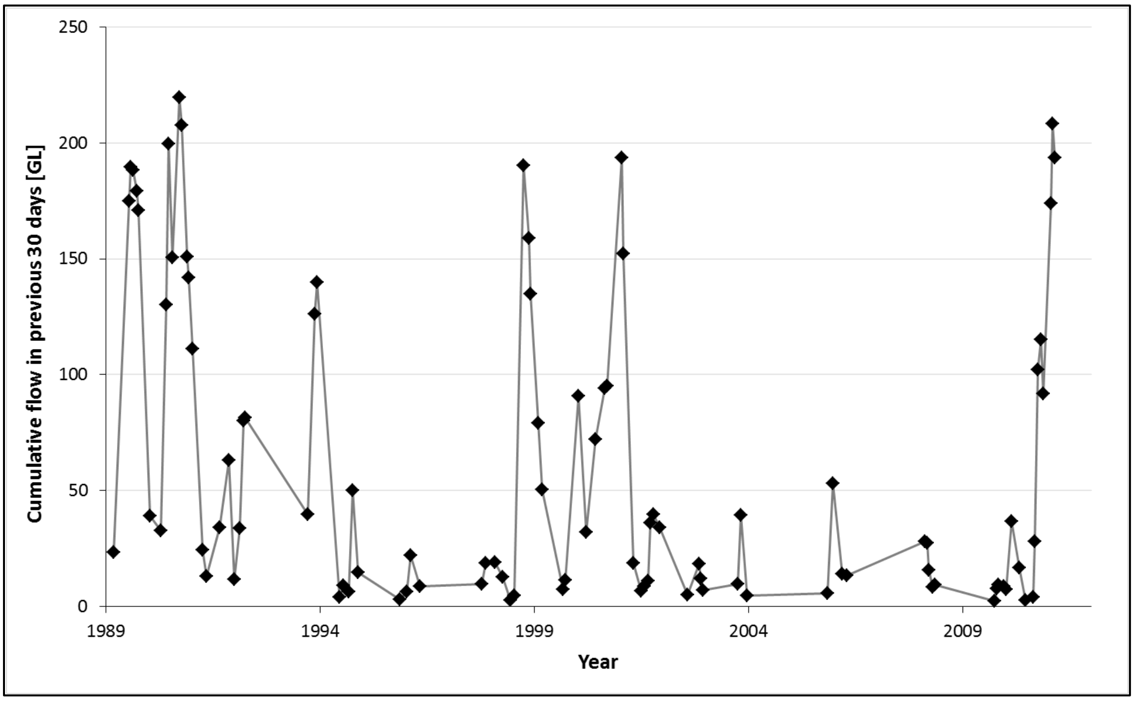
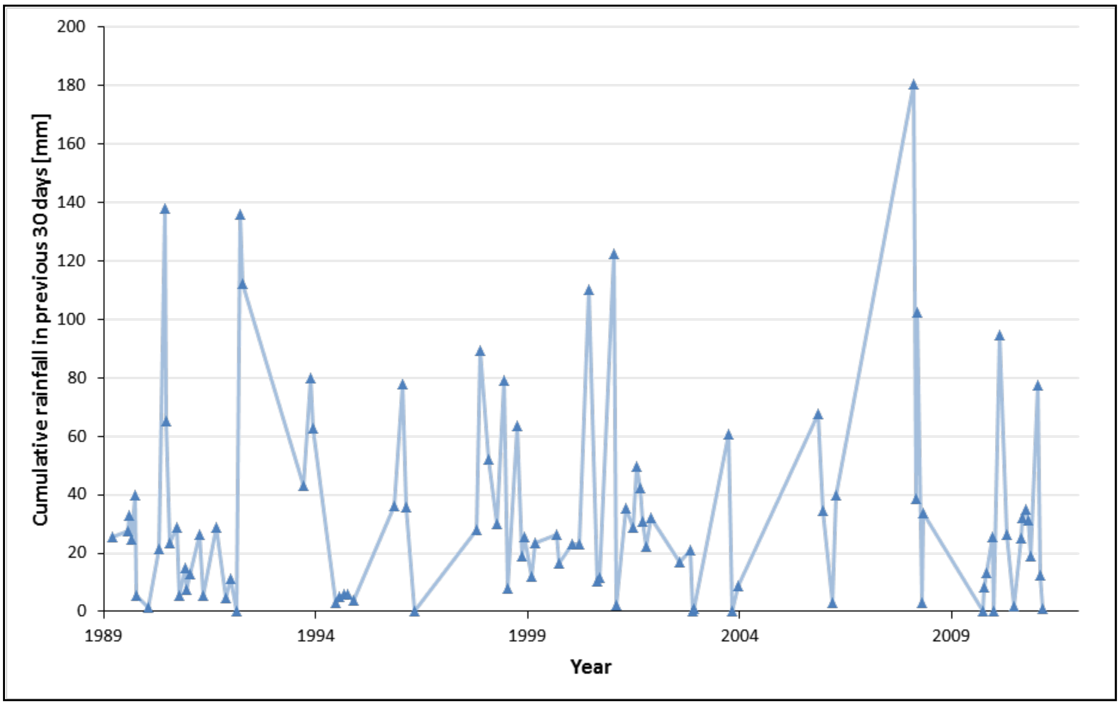


Figure 48: Cumulative rainfall (mm) for the previous 30 days, measured at Quambone, on the eastern side of the Macquarie Marshes.



3.5.5. Graphical Interface used for information platform for the Macquarie Marshes

Figure 49: Tab layout and display of data, showing the three main categories of data (boundaries, drivers and ecology) and then displaying some of the categories within ecology.

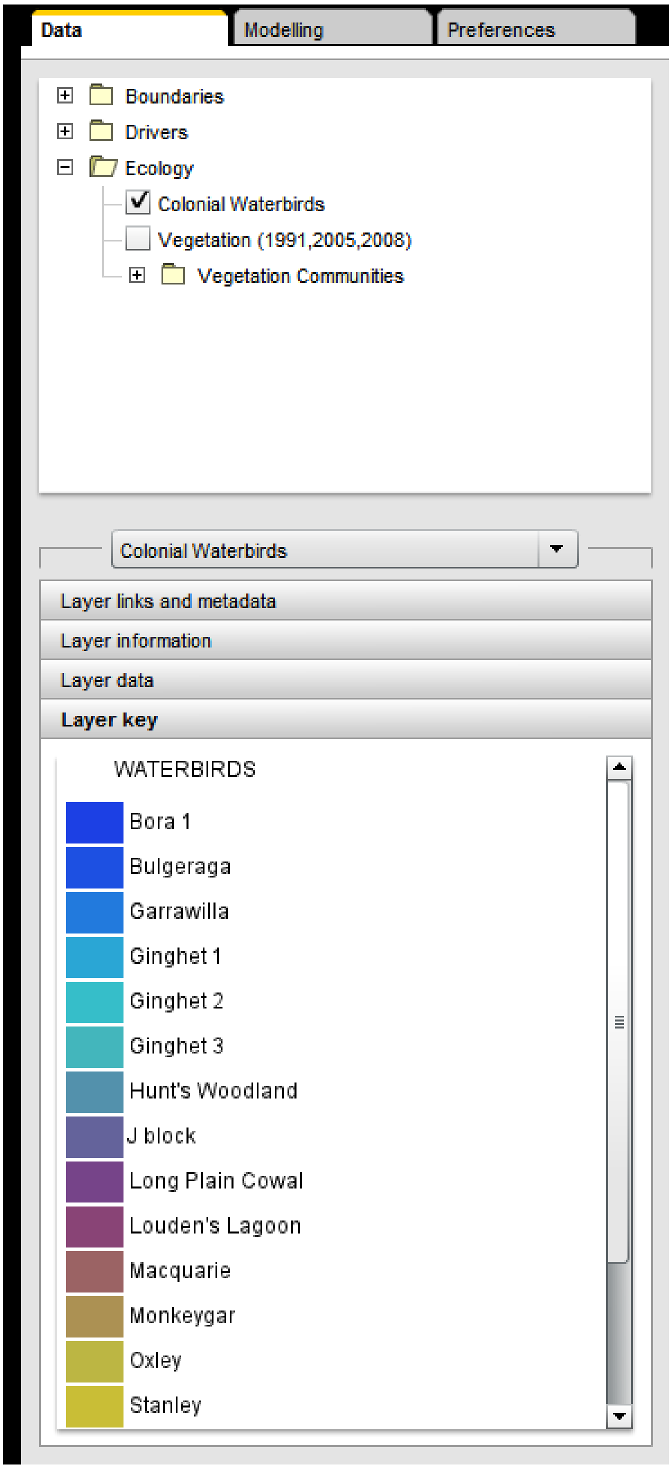


Figure 50: Visualisation of data through the Google earth interface

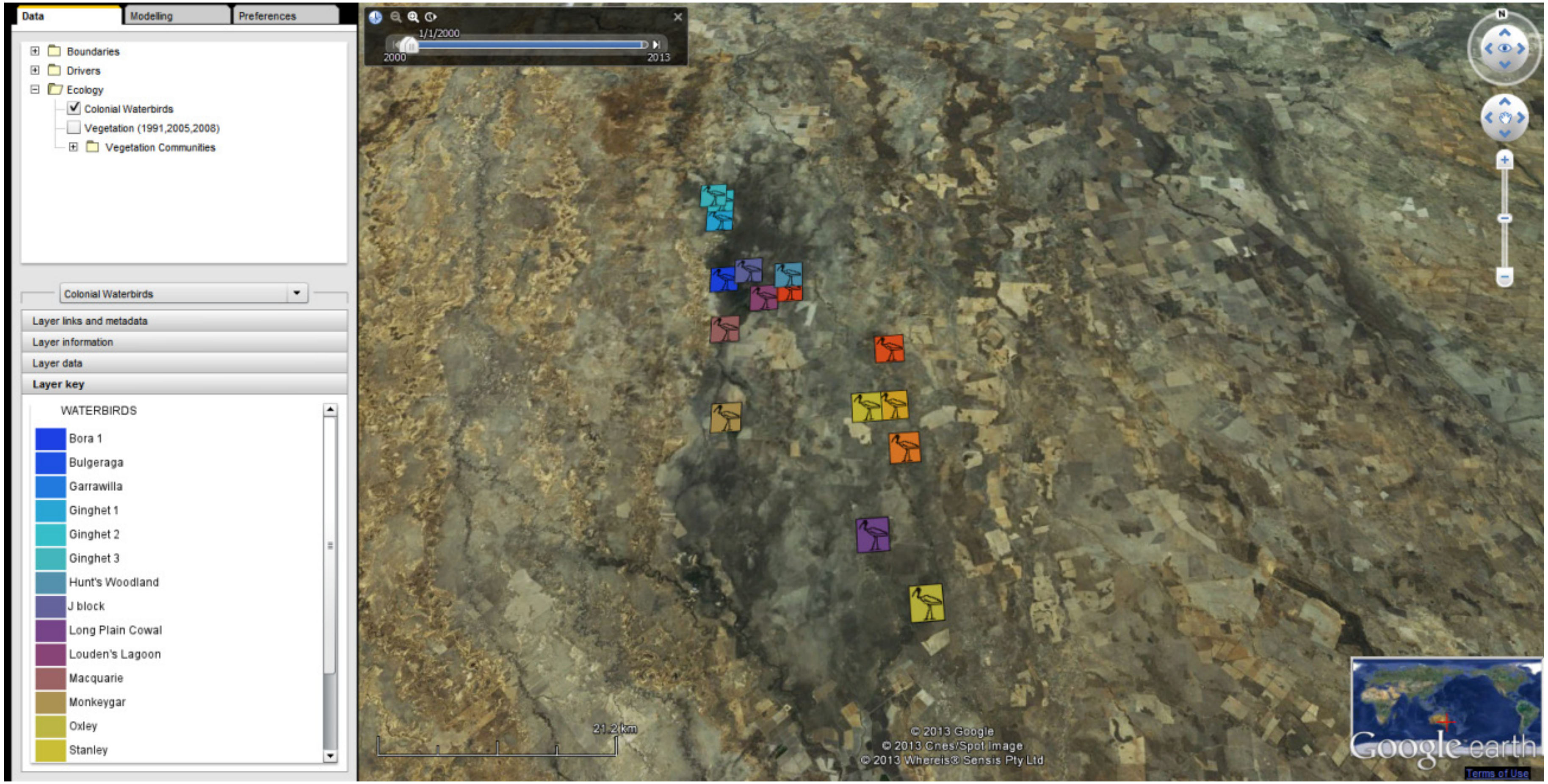


Figure 51: Displaying multiple data sets – showing the Ramsar site and the colonies of colonial waterbirds

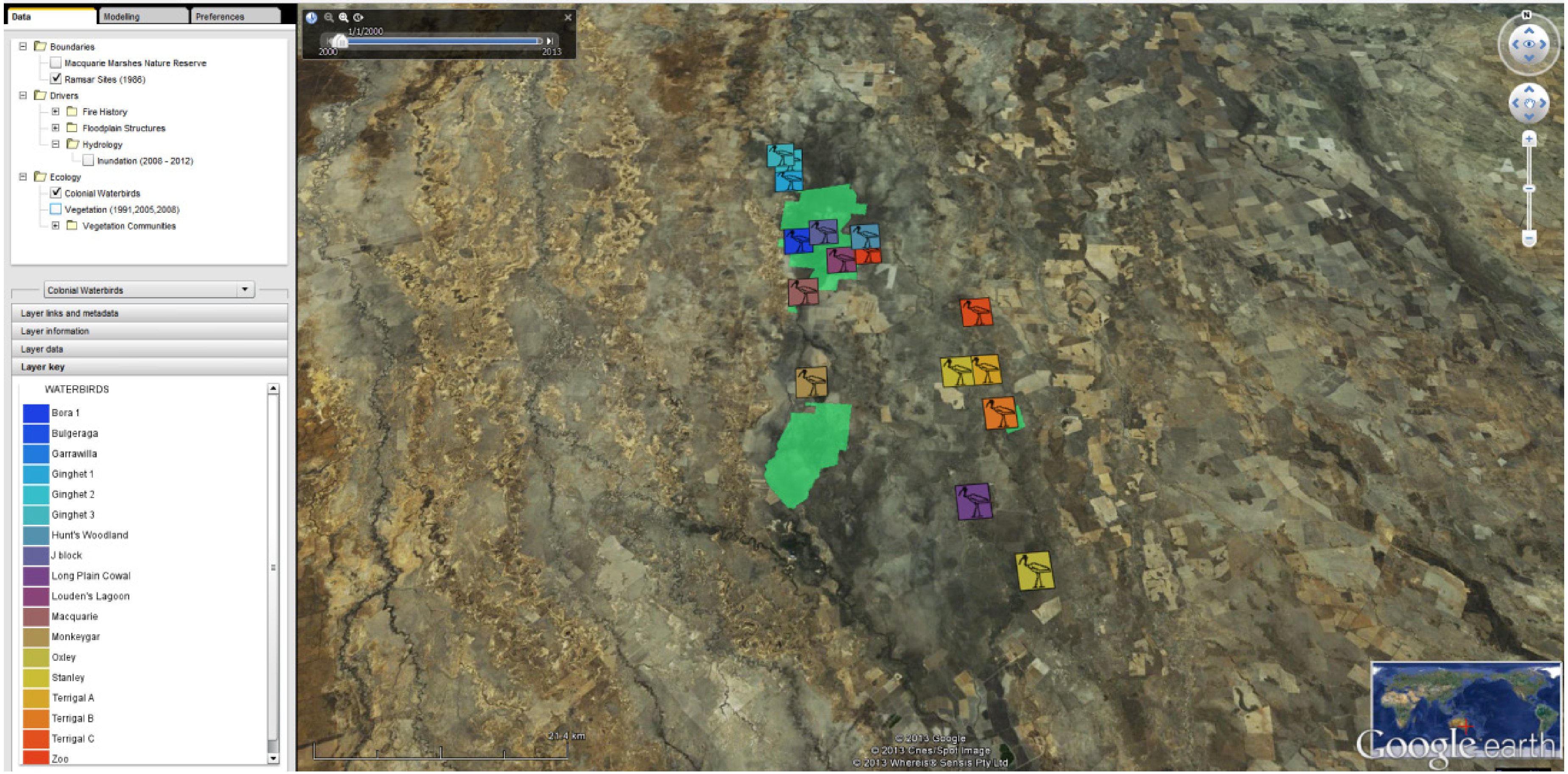


Figure 52: Using the temporal slide bar (top left) to display a temporal sequence of inundation extent

Figure 53: Retrieving relevant information from a loaded data set. A pane on the google earth image shows the area of interest when clicked on displays the type of data available.

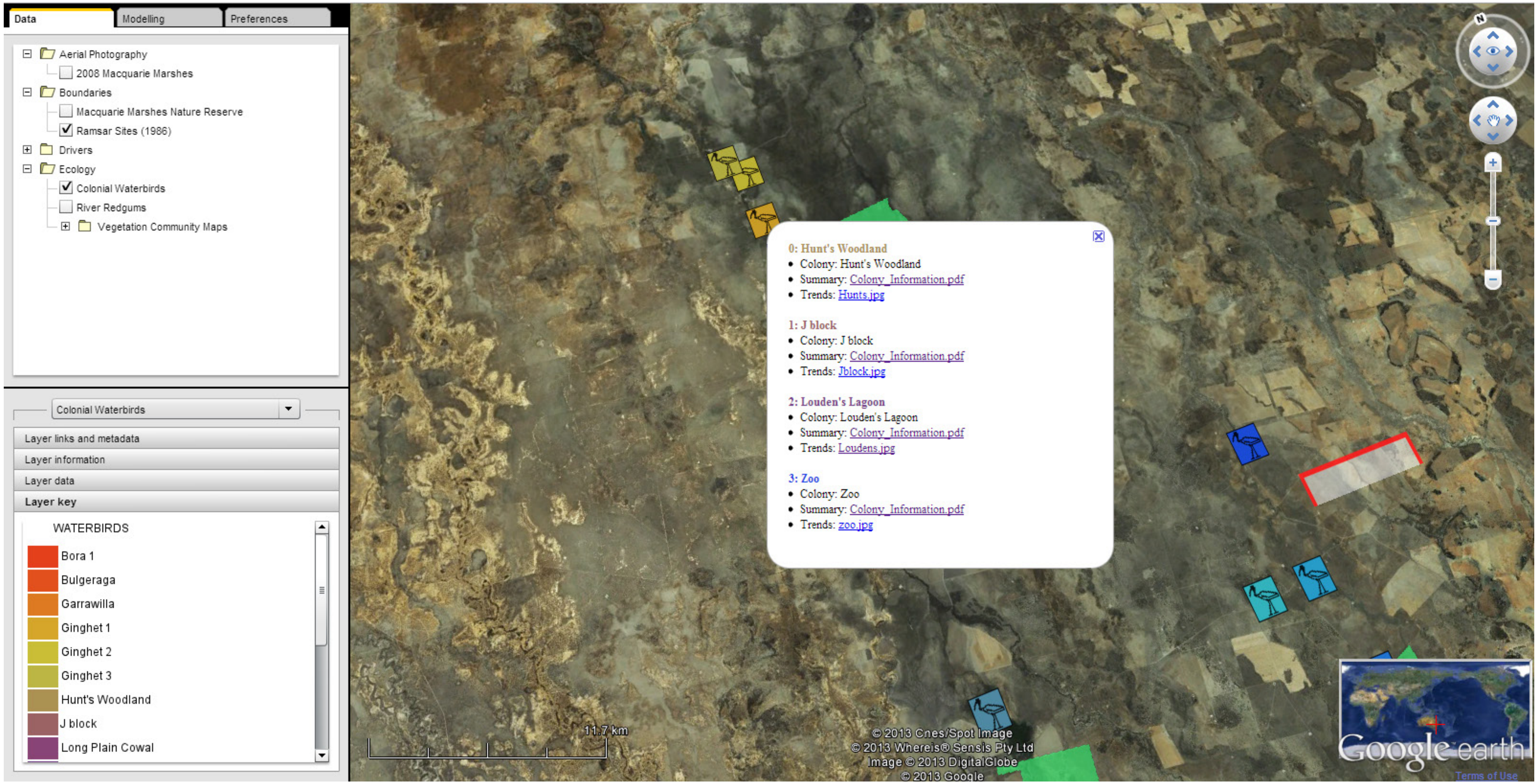


Figure 54: Dynamic modelling tab showing the flood modelling (see above) with different rainfall and flow variables.

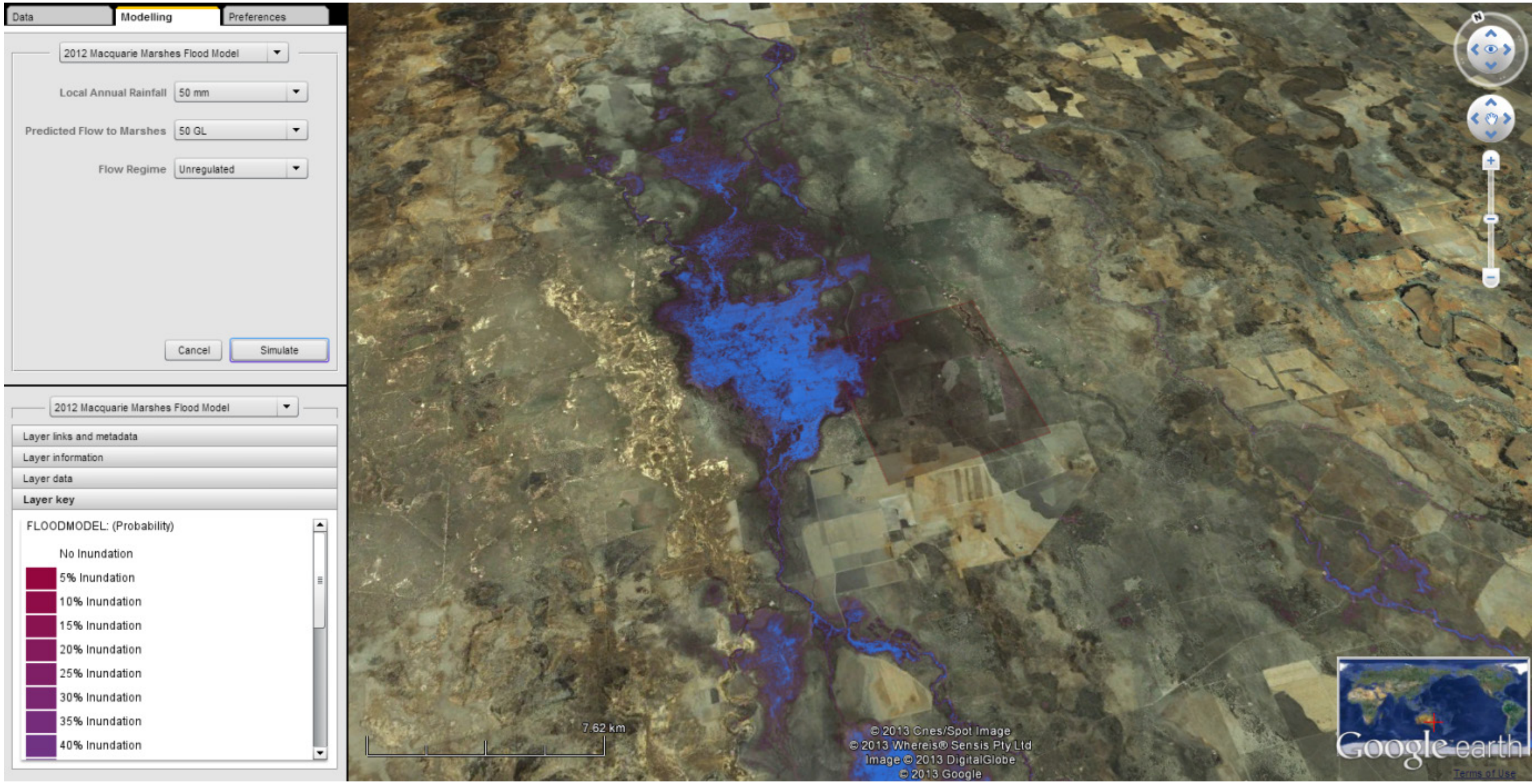


Figure 55: Backend interfaces – here are the details for organisation of data and access.

3.6. Review local knowledge

3.6.1. Introduction

This section focussed on documenting the local knowledge that graziers and government employees have gained from living and/or working in the Macquarie Marshes through the boom and bust cycles that characterize arid-zone rivers and wetlands. We sought to record the ecological observations of graziers and government employees over decadal time scales across periods of drought, flood, and changes in river management. We also wanted to understand how graziers might adapt to increased temperatures, reduced flooding, and more frequent drought as predicted with climate change. Landholders on the Macquarie Marshes have experienced extremes in these three variables and we are interested in their observations and strategies used under these conditions. We were interested in whether these practices may also help adapt to the possible consequences of climate change. The key changes predicted with climate change are loss of flooding, higher temperatures, and increased droughts. Landholders on inland rivers have adapted to extremes in these three variables and we were interested in recording the strategies already in use by landholders and whether landholders consider these will work under more extreme conditions.

We collected information to help develop and evaluate climate change adaptation for floodplain wetlands and manage water for irrigation and the environment. These interviews also served to help identify management strategies that can be studied further in future research.

In particular, climate change adaptation strategies involve complex trade-offs between the values different stakeholders associate with the ecosystem goods and services provided by floodplains and their wetlands. Climate change exacerbates the uncertainty associated with evaluating these trade-offs. By recording local knowledge, we will ensure that these valuable memories of past and present events can be utilized in river and climate change planning.

We asked participants for demographic information, and for information about their local knowledge of past and present events. Participants were asked about their farming practices and their adaptation strategies to deal with projected climate change (section 7.3).

3.6.2. Methods

We targeted interviews, rather than a broader questionnaire, as our potential list of participants was small (fifteen stakeholders grazing in the Marshes) and we wanted detailed information on the topic. We were interested in hearing of experiences, feelings, or opinions that cannot be captured through closed questions. We undertook face-to-face interviews.

We developed interviews to survey the local community (see questions below), with ethics approval through the University of New South Wales. We attended a resilience workshop organized by the Central West CMA on the 22-23 February 2011 and had informal discussions with landholders and government stakeholders. Informal discussions were also undertaken with landholders. Formal interviews were undertaken with eight landholders from five families, representing roughly 40% of resident landholders, with all of these families having settled for three generations. Ongoing interviews will be undertaken in 2013 beyond the scope of the current NCCARF project to extend the oral history for the Macquarie Marshes.

The interview was comprised of a series of semi-structured, open-ended questions that encourage participants to freely express their views without prompting in any direction. The specific questions involved were based on outcomes from the Jenkins et al (2011) literature review and stakeholder workshop, knowledge of the project team and informal discussions with stakeholders during ecological research fieldtrips.

In total, there were 37 questions developed after participant information questions. The remainder of the questions focussed on ecological observations, the history of farming practices and adaptation to climate variability. Interviewees were known to the researchers through our long association in the area. We phoned to discuss their interest in being interviewed, made a subsequent time for interviews and emailed in advance the questions.

Participants were sent an information sheet relating to the project and ethics approval. At the beginning of the interview we provided participants with background on our NCCARF funded project. All participants gave their written consent to being interviewed and for interviews to be recorded. All participants were asked the same questions in the same order and in the same manner. Participants were free to ask questions at any time during the interview and to refuse to answer any questions. Participants were asked if they wanted to make further statements after we completed the questions.

Analyses

Following interviews, we consolidated quotes under the broad areas of interview. We also represented a synthesis of quotes along a timeline for animals, fish and plants (see Figure 56, Figure 57, and Figure 58).

3.6.3. Results

Important parts of your country/ living in the Marshes

All participants say that wetland, floodplain and marsh areas are important parts of their properties. Some mention other country types as well.

"We feel very lucky to be living in the Marshes…to look out your kitchen window and there's 50 pelicans swimming around and you thank your lucky stars that you live in a magical place like this."

"The wetland area has an environmental importance as well as financial importance compared to dry land area. Mixed marsh areas are important. Just having that stock and domestic water stock and the mass of water in the system there is important."

"I love the flood country. When it's all green and everything's looking good. I guess that marsh country is special country, isn't it?"

"… when you take people down on the flooded country it certainly opens their eyes up. They just think it's a park area. Yeah, it's a unique place and all places along the marshes are pretty unique in their own right with big river gums and wildlife. They've all got their own character."

"[Referring to the marsh country] the key word would be high capability, that's (how) I would describe it. High environmental capability and its economic capability is outstanding… In wetland country, you can probably run five cows to an acre. On dry land country, you might need four acres to run a cow."

"I love the flood country... (the) marsh country is special... I think you've got to say it's a privilege to own it… It's magnificent country... you drive around and you can't really see any better country anywhere... If you drive across Gibsons Way when it's been a good season, you probably wouldn't get a prettier road in Australia."

“Economically it was important to provide my livelihood that educated two children… the whole property worked as a unit. I couldn’t divorce one part from the other.”

“Well if I answered that I'd have to say, well, the flood plain is the most important… The marshes.”

“This is a pretty tough question… put the marshes but it's also the balance. It's no good just having flood coming in. You need the balance - when your flood country's not productive you need rain fall dependant areas… So you have the flood plain when it hasn't rained and then you have the drier country that responds a lot quicker than the flood plain. So yeah, having the variety of country will… Just having a paddock like that that's all inundated. There's two times that it's not productive. It's not productive during the winter and when it's just been flooded and it's just got water lying all over it there's no production in it for our business. But also when the floods aren't coming, it doesn't respond from rain fall. So you've got to have your stock elsewhere if there's been no flooding river for six to eight months. You've got a bare paddock. No matter how much it rains, you won't get any growth. Because it's aquatic plants growing on the flood plain, it's not - we don't have… rainfall dependent species.”

Specific events that stand out

Floods and droughts were predominantly mentioned as standout events.

“Large flood events and there’s been some erosion issues that stand out too.”

“The droughts stand out for me.”

“Just any of the flood events always have their own character. It's always - probably the older flood events more than the new ones because they took so long to come through, like where now they just sort of happen overnight.”

“We had a big bush fire here years ago and that was more scary than anything.”

“It's nice watching the water come through and just the changes in the country as it comes through.”

“The construction of [a weir on our property], that's an event to remember.”

“The dry time probably stay in your mind more than the wet years.”

“The flood in 1990 - major flood - was third largest I think from memory of recorded floods in Macquarie… We weren't really shut in… the '50s floods they were bigger by a degree of major magnitude… Their access was very restricted then because the roads weren't sealed. The roads weren't up to the same standard and the roads were washed out in a lot of places. In the '90s flood there wasn't that disruption for us. For further downstream there was… They were isolated. In the '50 floods, apparently, the access from The Mole to Warren was cut off and everyone downstream of The Mole used to come to The Mole and they'd take it in turns to get across to pick up the mail - it was brought out a certain distance from them. Then they'd have to boat across to get it. A lot of water (in the 1990 flood). A few things that stand out about it- a lot of kangaroos perished. Pigs... Yeah as I understand it. I don't have… any visual evidence of pigs being drowned but kangaroos - definitely big numbers of kangaroos perished. It was concentrated on islands… malnourished and diseased. I have a memory of about 1000 kangaroos hopping through flood water and a big splash. Major bird breeding events... That was probably… one (of the) bigger ones that I can recall.”

“Most recent drought... 2001 ’til 2009. Each day we got an environmental release at our place in the spring of 2009… Anyway there was a string of very tough years.”

Differences post-Burrendong/ Changes in flood features

Most participants observed that the water now moves quicker, some say it is due to the water running more in channels and not spreading out as far. (Some comment that this acts to exacerbate erosion in channels.) Natural floods were more frequent but shorter because there was nothing holding up and slowly releasing the water. Some say controlled flows dry up faster than natural floods and heavy vegetation slows down flood waters on the floodplain.

"I was in a channel the other day putting up a bit of fencing and you could feel the water pulling against you. I can never remember it running that hard, like I think because they just dump it out of the dam at x amount of Megs, then they just put a gate here and instead of being run on the full width of a channel where I've got full control over it."

"So next thing they're forcing the water through half the amount of area that it usually runs through. I think it just makes it run a bit quicker."

"I just feel they're a little bit quicker now mainly because the erosion is starting to find the channel. So naturally when you get a channel event, you get a quicker flow."

"The water's moving quicker…as plants grow up more and more it slows down again."

"It doesn't spread as much as what it used to (you) probably only getting half the amount of water over the paddocks as channel erosion is extensive."

"I think a natural flood was a shorter flood because there was no actual control. It might have been bigger but it was a shorter flood at the end of the day because water just came and you just let it, and there was nothing holding it up."

"Floods are less frequent now, because the dam controls it."

"Comes up and back down a lot quicker now because there is more control over it. One they've got full control over, like a bird release, they can shut it off tomorrow. For an example, that water could stop running within a week, it wouldn't be running and I don't think that - that's not good for the system either, it needs to tail out.

Used to dry back slowly, but it's fast now."

"Coming out of a drought and the floodplain looks like moonscape and you can imagine when the flood hits that, it covers the country extremely quickly as opposed to now, the vegetation out here, at the moment, it's definitely slowing the water up. Or you can run down the crack for three days before it… After coming out of a drought, yeah. It's absolutely bottomless."

"historically it used to flood out. It doesn't really do that much anymore ... since 1987 until about four years (ago) I noticed an accelerated decline (in core wetland areas)- more than what would have naturally otherwise happened because when those smaller (flooding) events happened in those drier years, the cream kept being knocked off the cake... for a short time I would say the wetland area was back to a quarter of what it was in the late 80s."

"… the worst part about short flooding regimes is it suits introduced species more."

Used to dry back slowly, but it's fast now."

"There used to be seasonal, short to medium floods when I was growing up (c.1940s). Burrendong Dam altered everything down here… water used to close the Warren Road… It used to come in through the Terrigal."

"On the southern side of our main reed bed, like once upon a time you'd bog your horse, no worries at all. It was silty but now you can get through there and it's not so much. Overall I'd have to say, it's probably not as boggy as it used to be. It was quite common to bog a horse."

"Most recent drought 2001 to 2009 and increased water extraction after Burrendong Dam was built the dam captured the medium sized floods. The cotton industry was slow to get going. It was still mainly family farms. It wasn't till the corporates got in in the mid - late 70s, early 80s then through the wet years in the 70s there was more water than they could use so the government in their wisdom, issued more water licenses and then the irrigators started putting on farm storages. So it's effectively two Burrendongs."

"(Flood are now) less variable… (and) shorter. That was again controlled by Burrendong Dam and as the irrigation development took over in the Macquarie Valley the incidence of flooding reduced… from about '74 on the frequency of flooding reduced. In the valley the irrigators were just starting to fire up really well in the beginning of 1917 and a lot of people got wiped out in the flood in '74 and they weren't so keen to get going again for a few years. Then it gradually built up as the water use increased, the available flows to the Marshes reduced. The effect of managing - we still got the little floods and we still got the great big floods but those beneficial in between floods (were gone)… up until 2000. They've changed since then because of the increase in water allocation to the Marshes environment."

"(Flow velocity) increased. The reason it increased was that the European Carp came through and cleaned out all the growth in the channels and enabled the water to move more swiftly - shift sediment and erode the channels deeper."

"… what describes a change in the flood features best for us is the removal of the medium floods. We still receive the big floods and we still receive the little floods."

"… before that dam… I remember going out there and it would be… four or five days to go through one paddock. Now… you're watching it and it'll disappear

Changes in channels and erosion

Participants commented that erosion is currently a feature of the system. As mentioned previously, channelling is exacerbated by an increase in flow speed.

"Erosion is definitely a feature of the system today. Mainly in the channels, the channels are increasing. Mostly off the Buckiinguy Creek system- it has two issues- channel choking in some places and channel breakouts in other places. It's definitely happening more than it used to. The Buckiinguy was a much freer system 20 years ago, but I don't think it was there 100 years ago."

"Since 83, I've seen a lot of channel erosion… Channels have gone from only being six inches deep to two foot deep. Right through the main Gum Cowal channel, all the way through (the property), all the way through it.

I think erosion caused by little flows… probably European Carp haven't helped a lot… I think the water runs a lot quicker now because it's not natural."

"One of the Oxley managers, in the 30s blocked the Monkeygar. There used to be a branch that ran across to the old Macquarie. It had the highest impact on the old Macquarie the channel blew out quite a lot; it's definitely a lot bigger now. That was a major change that could have changed the function of the area."

European Carp came through and cleaned out all the growth in the channels and enabled the water to move more swiftly - shift sediment and erode the channels deeper. Well the channel profile went from that (indicates saucer-shape) to that (indicates U shape). Yes all of them, everywhere. Everywhere I noticed it through the Marshes… There was certain areas, because of the amount of sediment that was shifted with the changing channels that became… deltas where it spilled out - became very boggy and certain places in the river on the bends - on the inside of bends - became very treacherous. Water holes were filled up with sand. Other places where there's reeds growing on the edge of the water it became very silty and boggy."

"An actual flood as distinct from a controlled flood had a rapid build-up and a slow draw down whereas the engineered floods (have) a very defined profile."

"The Bulgeraga Creek on the upper reaches of it has got the profile of a new channel - new water course. It would never have been anything other than that because that's what it is. It's a new channel. The Monkeygar is the same - same story. On the Monkeygar Creek upstream of [Unclear 1:25:07.5] and again when you get downstream of the ... It's a new channel. The Macquarie has - has got the shape of an old string and I think over time those others will develop that profile if - revert to that meandering, slow-moving waterway. Whereas now they're a high speed highway."

"Depends where you are in the system. Yes I can remember a time when the channels here weren't as steep. So yes but I still think that's a bit of a generalisation, that question, if you - depends where you're go in those systems (Bora and the Gum Cowel). Could be that however wrote that question accessed those - some areas on the Bora that where there is active erosion and a steep channel bank so not so much the Gum Cowal."

"(I've notice erosion in) all the main streams… not the Bulgeraga. The Macquarie, active erosion and the Monkeygar… the streams that carry the low flows, they're the ones that are eroding… Constant low flow and they miss out on that drying out phase… the Bulgeraga's not eroding because it's regulated… at the top… It's not actively cutting. Whereas the others are that don't have any regulation."

"… some areas are suffering from siltation, change and flow rate damage… On the southern side of our main reed bed, like once upon a time you'd bog your horse, no worries at all. It was silty but now you can get through there and it's not so much… Yeah, it'll dry up… because of the drying out phase… There's nowhere else in particular that there was the silt as there was… at the reed bed… Overall I'd have to say, it's probably not as boggy as it used to be… Yeah, well that's what I'm thinking when you ride your horses through the channels and it doesn't seem you can do it with a bit more confidence… They could come and go… you'd go for years and be very nervous about entering the channels and then… for years and it's no issue."

Water quality/ water quality in flood/ water usage/ water usage in drought

Most comment that the wetland functions as a filtering system, in that the water coming out of the marshes is always clear. Some have observed tannins in the water. All agree that the water has never smelled bad or suffered with algae.

"I've been surprised by the colour of the water, it goes into the swamp looking dirty and it comes out the other end clear. The river's carrying a bit of silt from where it's coming from. I don't think it has been different in my time."

"When the water used to cut off the Warren Road the water was sort of clear."

"It was good water because once you run through the system they go through it filters."

"The water is nice and clear by the time it gets to our place."

"Water out of the dam is clear. Some water out of the creeks looks dirty. Sediment to a certain degree. It turns a bit red, I've seen it purple where we've had Gum leaf stain by Gum leaves and things like bark and that and it'll go purple or amber… if you haven't had a flood for 12 months, if you haven't had water through the system for over 12 months you'll probably see the bark stain more because of the bark that's on the ground hasn’t been [leeched] at all.”

“I just say it's milky coloured. Generally, it's not sandy. It's not clear… it depends where you are. Depends on the flow, if there's tributary flow coming down, it's muddy, if it's coming out of the dam and coming out of the red bed it's clear… Well it just depends on the events beforehand. Like whether we've gone through drought and where the water's coming from.”

“You couldn’t say it stinks... it’s always been a pleasant smell”

“(Water quality) depends (on the) stage of the flood. I reckoned I could pick the source of the water. Coolbaggie Creek was just about soup - very dark, very heavy sediment load. The Talbragar was the next; it carried a lot of red water. The Little River was not nearly as discoloured but still quite dark. The Bell River was nothing compared to the other three. Water release from Burrendong Dam was clear. Then after the water arrived on [our property], within 200 or 300 yards of the channel ending and flooding starting the water would be clear. It's drop all its sediment. There was a rapid build-up of sediment around that area forming a delta. Then as the channels eroded deeper and the water started moving - flowing more quickly - that discoloured water - the sediment load was carried further downstream. So it wasn't all filtered out.”

(Of black water events) “The only thing I could think of - black water were the first - after a dry time all the water holes - the first flush out of the water holes was pretty ugly… I haven't noticed the fish kills. Not in the Macquarie… (the water looked pretty black from) Tannin… I think more than anything.”

“Not algae as in blue green algae in the river but large amounts of thick algae that forms in the still water when it's at a reasonable depth. When it dries up it leaves almost a tar like residue on the ground surface. I think it came after it's been summer floods.”

“The effect of the European Carp on the water quality was very pronounced. You could see running water in a reasonably deep channel - you could see to the bottom in say three feet of water. After the Carp came through you'd never have been able to do that.”

“Never drink it myself. Makes me very thirsty. Besides we used to, before they started growing cotton up stream, and then the thought of the chemicals that may be in the water from the cotton industry. If you needed to drink you'd wait until you got home. Boating, fishing, enjoying, but not in any way for domestic use.”

“(Water in the Marshes) can change but I wouldn't say it's ever been smelly. It might smell different… No visible change. If you're doing river crossings, the water's same as it was.”

“The bore here at the house was only ever used for the house and two years into the drought, the cattle that run on the floodplain didn't have any water. The river had stopped completely for a period of time. So for the first time ever the cows had to… (drink bore water)… I think it could have possibly supplemented cattle in the 1940 drought and in the early 1900, 1920 drought. Prior to the 1940 drought this was the only time that we (supplemented) - 2002 until 2009. So it was pretty significant to have to give the cows access to the bore. That had always had access to the river.”

“Well water coming out of the dam is clear… every time I look at the river, (I) can tell if it's a trib flow or out of the dam- it's artificial water. (Right now) it's clean water compared to the trib events. (There’s) no difference (to pre-development water colour on the floodplain) because it's filtered… The sediment load increases if it's coming from downstream of the dam. Or it decreases if it's coming through the dam or over the top.”

Animals with flood events

All participants agree that swans are synonymous with flooding events. Bird life in general is most commonly associated with flooding events on the Marshes. Some note changes in animals they have noticed over the years.

“Swans are always nice… Swans and Magpie Goose is always a bit of a kick… You see the swans and then you see the little ones and that's nice… Yeah the swans are probably the pick.”

“I've noticed a lot of swans- just trying to think what year… must have been about 2003, must have been wet.”

“So you might see a heap of swans fly up off the river and the kids are pretty excited about what they see out there. Yeah, it is a good time. Like you can see the country's productive and the animals have done well, it is a nice time.”

“Waterbirds, snakes in abundance, fish, turtles, water rats, centipedes, frogs, lizards…don’t see these in a dry year.”

“We've had, these last couple of seasons, these big black butterflies. I can't remember seeing them since the 1970s.”

“Used to be a lot of freshwater mussels in the Marra Creek. There were more turtles around in the 90s. I think feral foxes and cats get their eggs now.”

“No more frogs than usual during big floods, the birds were eating them. There were a lot of snakes, red bellies, black snakes, yellow bellies… used to see a lot of turtles.”

“Bigger variety of bird life.”

“See turtles around, never in big numbers.”

(Of turtles) “Yes, always.”

“Less snakes now, apart from this year. (In the) early 70s (it was) not uncommon to see 20-30 in a day.”

“Been a decline in black snakes - red bellied black snakes… not disappeared but declined in number. Apparently the numbers are building up again now… in the '60s and '70s there were lots of black snakes. Probably the '81/'82 dry period was the start of the decline. Just can't quite place it when Peter Harlow was out there catching snakes and they were dime a dozen. You just had to walk a few yards and pick up another one. I think that would have been late '70s.”

“Through the 70s there were a lot of frogs- all you did was wander around the Cowal and just turn the logs over and there would be just as many as - the right type of frog whatever it was we used to catch. You get as many as you like… Stopped getting so many frogs and snakes late 70s, 80s- Might have had something to do with the droughts because everything was so hard. Like for them to survive would have been just as hard as everything else, I presume.”

Regarding frogs: “Huge numbers at times and from what you're saying they're just about back to what they were. They come and go with the floods... I'd say there was a decline in frog numbers that coincided with the decline in the black snakes that would have preceded it but numbers have built up. I haven't been there at night and that's the only way I know how many frogs there are as a flood moves through and you can hear the chorus building up as the flood water moves across the country. It's amazing.”

“In the 80s-90s (during the big flood) dragon flies used to be thick. You used to go out at sunset and just the front lawn and around just humming. Even on the big flood last year, like we had mosquitoes but there weren’t that many dragon flies around.”

“There's still plenty of dragonflies if you get the right conditions.”

“In the 70s the mosquitos were real bad... we put a horse rug over the milking cow because the mosquitoes were about. We had to light fires for the horses and dogs. They were pretty bad this year but they weren’t that bad. A few more efficient chemicals running around now, to put on the animals too, mix up sprays and...”

“Mosquitoes only bad around the edge of the Marsh. Very few mosquitoes out in flood water. Must be enough predators to stop them breeding successfully. Dragon flies in big numbers at times. With spring flooding large numbers of dragon flies. Snails - the freshwater snail. Pick them up in bucketfuls as the water dries up.”

“Fresh water mussels in the dams, not a lot.”

(Of fresh water mussels) “Yes I don't eat them but there's always a lot. I haven't noticed a change there. Yabbies at times; huge numbers in the flood water. Noticeable when there's a change in the water quality and they've got to get out. They get out onto the road for some reason. I don't know what drives them. You'd soon go and pick up a bucketful in five minutes… that's at the peak of big floods… I'd never really worked out why these things happen. Wanting to get to the other side of the road and - but you'd see them halfway up a Cumbungi stalk. They'd climb to get out of the water. Doesn't seem to be a natural thing.”

“We used to love digging them up… it was a bit of a competition… I haven’t heard of anyone eating them.”

“In the early 70s in the Terrigal creek (you) had to wear shoes going across because the yabbies were that thick. You could just walk along and pick up the ones you wanted. I remember them being fairly thick in the Marthaguy but then there was a chemical spill upstream and that quietened [*sic*] them down for a while. But they are coming back, like if we get a rain event now you'd be quite easy to go and catch a few of the yabbies at Marthaguy.”

“I haven't seen any (freshwater crabs) for ages. I haven't seen any for about 20 years... I remember the fresh water crabs more from growing up on the Bogan during wet years there. I'd see them running around on the - sideways of course - on the clay pans there into the water… on the edge of them - where the water spread out…”

“It is nice to see the birds there when you do see them. We don't really have much colonial nesting in there but sort of the more non-migratory bird types. So the Buckiinguy seems to be a good place for that. It's always nice, that's something that sticks in your mind to see those.”

“Snakes in abundance… mostly blacks.”

“Fish, turtles, water rats, centipedes, frogs.”

Animals in dry periods

“(There is a) bigger percentage of roos during dry periods… man has put water on our place alone… over 6000 acres there's probably a watering point ever two kilometres. If we weren’t here the roos would have had to hop 40 kilometres to get a drink… I still believe there's a lot more roos than there ever was.”

“When it gets dry, the roos will move in, move there by thousands.”

“(During dry periods) you don't see any fish because there’s no water. You don’t see any frogs… turtles, you don't see any… snakes are pretty sad because there's no frogs… Birds have taken off looking for other water.”

“Lizards should be in there… Well you actually see them during both (flood and dry) but there's less around.”

Changes in fish species

"… there was a lot more (yellow belly and catfish) then than what there is now… there was cod and everything… There's carp, a lot more carp now."

"I remember when… the kids were little (c. mid 1970s- CS) and dad went down to Frank Johnson's and they pulled about a hundred yellow bellies out of Williwarrina"

"I just remember when I came home from school, carp were a big issue… in the 80s, I suppose - because I don't remember much made of them before that. I think the carp's become a big issue in the 80s."

"I remember catching an eel years ago… in the 70s, might have been 80s … you always see carp and that in the channel when it dries up but never actually seen any Yellowbelly or natives… whether they were too smart and got out because they realised what was going on and bolted before the (water dried up)… I never really noticed (native fish)."

"Big numbers of Yellow Belly in the early days, occasional Cod, quite a few Catfish. I haven't seen or caught a Catfish for 30 years. Yellow Belly are reduced numbers but Cod have increased in numbers."

"As a child, cod, cat fish, yellow belly were prevalent. I'd never seen a carp prior to 1980. We probably still get the full range of waterbirds but we get them a lot less often. There's less breeding events for sure."

"In the 1974 floods (carp) came through then. They came en mass - big numbers - migrated up the Darling. Well they were up the Darling in the Barwon and then followed the Macquarie channels up - it goes like that."

"Fishing became a non-event after the Carp came through. It was every time you dropped your line in all you'd catch are Carp. You didn't want to eat them. You'd pull the drum net out and it was full of Carp - 30 or 40 Carp. You didn't want them so you just gave up. The Yellow Belly certainly decreased in number from that event. The Cod have recovered and gradually increasing in number. I don't think they're breeding… locally I don't know."

"Cod, cat fish and yellow belly were prevalent… Now rare, all three of them. And carp, the carp's come along with river regulation so that they weren't about (before). I think (their arrival) might have been the mid-80s... I'd never seen a carp prior to 1980. Yeah, well I'd never seen a juvenile native fish but there's definitely more juvenile carp. Gambusia… wasn't until the mid-80s we saw them… I think (the arrival of Gambusia) was a lot more recent. I don't think it's been - the last 15 years but maybe they were there and I didn't know about it."

Changes in bird species

"It's only in the last three to four years that I've seen large bird numbers and water hen numbers. Even though the ibises and things like that don't have a rookery in there, there was still… lots of them. It's only in the last few years that those big numbers have come back, in these last two or three wet years, there's lots of water hens in there at the moment."

"I know they can get a lot of brolgas (in Buck Swamp) at times. I know that they will breed there. So I've noticed that… probably early 90s. I noticed brolga chicks there."

"I suppose with the big floods they just hang around for a while, you get a bigger variety of bird life… Especially if it's a bit dry elsewhere, like we haven't had Magpie Geese here for a few years, we used to get the odd ones come through but they've been a bit absent over the last four or five years… swans probably haven't been as prevalent… Pelicans haven't been around like they used to be… They come and go a bit the pelicans. Just depends how much water is about. I think a lot of it is what amount of bird life you get because if you've got a wide area that's been wet, naturally your bird life - any animal life… go wherever they please. But if it's dry elsewhere on the continent and we get a flood about here, they seem to know."

"I've seen down on the lagoon area, I've seen probably up to, I don't know, 20 pair of swans down there… 10 or 15 years (ago) (c. 2000)… It clearly depends on the size and the length of the flood as to what comes and goes."

"White Ibis, Glossy Ibis… Straw neck Ibis, Whistling Ducks, Cattle Egrets, little Egrets, intermediate egrets, large egrets… Royal Spoon Bills, Yellow Bill Spoon Bills, Tern - nice Tern. Might have to get my list out. You want them all? Stilts, Reed Warblers. Lots more - 143 different bird species have been identified on [our property]. I can't list them all… all those ones I've known there have been common right through. The occasional visitor was a Jabiru who took up residence there. Sea eagles and in the last 15 years there's been an increase in the number of magpie geese. I hadn't seen or heard of them being there since probably the '50s. They've come back. One bird that has just about disappeared would be the Bustard - been pretty well consistent in their presence. Plenty of emus all the time…"

"'74 was a major breeding event. The colonial nesters were just right on the boundary [of our property]. Well they were along Monkeygar and Macquarie River but they weren't actually on [our property] apart from the ones - the Cormorants and not egrets but mainly Cormorants... Access by boat gave me a lot bigger picture. So I can't really say that it has changed. It's just been more accessible. There was a reported decline in bird breeding events through from '70 through to well in the '90s. I'd gather that it improved a bit since then."

"We probably still get the full range but we get them a lot less often… they're still returning but they're not returning as often… you get the environmental flow once a year. You get the birds once a year. There's less breeding events for sure. With the last few years it's... Only been one breeding event. (Brolgas are) always here, wet and dry."

Plants with flood events

During summer flooding events water plants recover faster than during winter floods. Some plants respond overwhelmingly to flood events.

"I think you see them pretty quickly if it's the right time of year. Like if you get a warmer flood, sort of spring time flood, you see your plants naturally a lot quicker."

"In the summer time, I guess they visually stand out three or four weeks after that, you can really notice the greenery from those, I suppose is a good way to put it."

"The budda pea (*Aeschynomene indica– CS)*… is pretty neat, it turns up every now and then and… eight foot high and you can't see nothing through it. Incredible plant… cattle love it… it's a legume apparently. It was so thick here that you couldn't see… three foot in front of you… it was pretty scary… [our son] and a couple of mates went out there pigging and he said they'd be on tracks through it and he said your dogs are disappearing. He said you'd hear something coming back through it and you didn't know whether it was a dog or a pig coming at you. He had nowhere to go because you're on a… track. (It was growing) up on the Gumtrees… It's just not there now… whether it was grazing pressure with sheep and that through the drought, I don't know. It's just disappeared."

"I'd have to say the reeds that have come back with the recent flooding has been very noticeable... we ride out into a paddock… and I say, oh, there's no reed here and he says, well yeah once upon a time this was all reed. So that's amazing to me, just the thought of that paddock being full of reed."

"Water Couch (has) no response in the winter time. Come the end of September you've got - it's happening earlier now; it must be warmer- you've got significant growth on Water Couch and it will grow up through a foot of water in a week. Tremendous root reserve in the soil where it meets the water and the nutrients are there.

"The reeds are not really dependent on flooding to shoot and grow but… without the flooding they'll die off. They'll die back."

"The aquatic plants, they will come within… 10 days - they're noticeable within 10 days of flood water coming through. Marsh Buttercup… Cumbungi and Nardoo are both - well the Cumbungi is a summer - it's triggered by the water in the spring. The Nardoo is a different one. It's more marginal flooded country. It's not a wetland species in my book. It's a marginal one."

"(There's) a tremendous response to flooding at any time of year but more noticeable in the… warm weather."

"No change (in number of species)"

"Response depends on a lot of things. What the season was like prior, whether the root development is established enough to promote the growth, whether the plant goes under water or like to a certain depth or what time of the year it is… you get a July/August flood and you don't get any response because you're still getting frosts until October. So we haven't experienced a change in temperature since the dam went in or development... so it's quite a toughie, that question"

"After the drought, it did take a couple of years for the country to… establish its root base again… so it wasn't instant… If you were doing this interview prior to us having a couple of floods, we'd say, yes we have noticed a big change in response to what it was like before but now that we've had three good years the response is no different. Just add water and it grows."

"I'd have to say the reeds that have come back with those flooding has [*sic*] been very noticeable… all through… We've got the main reed bed and we've got a couple of paddocks. I'll be year 20 years at the end of this year and there's paddocks here I've never seen reed in but there's reed in there now so that to me is pretty significant. But it has been particularly good, it's not… a result of the events… So if the rain fall went back to average and we still had the environmental flow… I don't know… we possibly wouldn't be getting that response. So that's a bit tricky."

On differences in plants pre- and post-flood: "Of course there are (different)… Aquatic as opposed to just roly-poly and moonscape."

Invasive plants/ Dryland plants/ Plants in dry periods

Both dryland and wetland plants were mentioned as invasive and/or a weedy issue, all participants agree that there was not much to be done about them, and they can only be left to run their course. A few comment that dryland plants are of less concern as they are less persistent.

"We have problems with wild turkey bush. I think it's more known as Golden Doddler (Golden Dodder- *Cuscuta campestris*- CS). It got going quite substantially in Buckiinguy and its bit toxic to animals. It upsets the liver, makes them have trouble to process protein. If (it) gets into their diet, it could kill them."

"Lippia (*Phyla canescens*- CS)… is a problem but it seems to have got to a certain size and hasn't spread for a while. But it'd be interesting to see what happens with that.

Some of it's been under water for a few years, the last few years now for quite some time. It's going to interesting to see what the lippia does after these last couple of big - last few big events."

"… we call it a native weed, Eumang but I think it's part of the wattle family. I think some people might call it black sally wattle (*Acacia melanoxylon*- CS)… To me it's a major threat. It's a threat to the flood plain areas… we actually got funding to do that with the CMA project as well… It'd be hard to get permission to clear it mechanically so we did it chemically. We just spray them."

"Eubung's probably increased… River Cooba (Acacia stenophylla- CS)… Well this one's called Eubung. The other one (presumably referring to Eumang?- CS) is long leafed - it's an acacia. It's a woody weed up in the southern end of the Macquarie, up in the Marsh areas."

"There's plenty of Eumung- River Cooba showing up… with the change of flooding regime… more prevalent now than it would have been."

"Gum trees are an issue on their own because of the loss of the medium sized floods they've germinated, their survival rate has increased and we've removed fire from the landscape - there's a lot more red gum generation than prior to Burrendong being regulation or up grown development or whatever."

"(My dad)… was a control freak… when we were first married (1960s)… when I'd come home we used to spend days and days cutting burrs… it was the Bathurst Burr (*Xanthium spinosum*- CS)… we did use pesticides in the end. Nowadays we don't, there's not much you can do about it… A few years ago that would sit there for a while but then they've gone off again"

" We've fenced the lagoon area off to try and help the couch grass (*Paspalum distichum*- CS) there at the present moment. Yeah, I think it's - it certainly helps I think."

"The black roly poly (*Sclerolaena muricata*) can replace (all other vegetation)."

"… people put down black roly-poly but it's a come and go plant, where (as) Lippia it's here to stay."

"… the worst part about short flooding regimes is it suits introduced species more."

"Lippia… in the 90s… we'd go out and you can see this little patch of it. You think oh yeah and not worry about it and then it's just everywhere."

"Roly poly is an issue in some places. Bathurst Burr is definitely (an issue)"

"(After a flood, underneath eucalypts) it'd go back to grasses."

"The plant composition of the vegetation varies according to the flood regime and if you change the flood regime you'll change the plant composition. Roly-poly, goosefoot, barley grass- lots of things would grow if you take the flooding away but they're the first plants that come in and establish. In the southern Marshes what used to be reed bed it's taken probably 50 years to go through that transition to a grassland of native grasses. You just get that established and someone sends down a big flood and wipes it out and you've got to start again."

Management of dryland weeds: "No it was just something you adapted to I suppose. It did but I can't recall a change in management… you could say it reduced stock numbers."

"Lippia - love it. It used to go out on the lawn. Didn't introduce it to the Marshes."

"Probably biggest threat that's facing a lot of the Marsh country - the marginal flooded country in the Marshes. Noogoora Burr (*Xanthium sp.-CS)* I think it's been there since the 1850s ... It builds up and then reduces depending on the season - depending on the flooding. It can be controlled."

"(A property manager) first drew my attention to (Lippia)… which would have been about 1981 or 2… I hadn't seen it in the Marsh before then but there's been a gradual increase. Yeah it's competitive and it's toxic to stock and it's undesirable and it's bloody hard to control… well impractical. It's probably increasing but the good thing - one thing that'll stop Lippia spreading - or not spreading but from growing - is water - deep water - two foot of water anyway."

"(The presence of Lippia) probably hasn't changed but it's just got harder to deal with as the flooding has become less frequent... I'd say (it arrived in) the 70s but for me they only became noticeable in the early 80s… main control method is grazing to promote competition from other plants."

"That's it. Roly-poly - the dry land species have invaded the floodplain with the removal of the medium sized floods."

"The livestock are putting increased pressure on the good plants. So it's restricting their opportunity, e.g. reeds, to survive and spread because of the invasion…"

Plants in the Marshes now/ plants in reduced numbers

Recent regeneration of reed beds seems to have made the biggest impression of participants.

"I'd have to say the reeds that have come back with the recent flooding has been very noticeable..."

"Reed beds were reduced up until recent floodings… these last two or three wet events over the last two or three years - the last three years anyway, the regeneration has been fantastic."

"Cumbungi is growing back- had disappeared with the drought."

"There seems to be a lot of duckweed on top at the present moment… and the yellow flowered water plant too, a fair bit of it about too… I'm hopeless on the names."

"The river couch is probably backed off to what I can remember being here."

"Red Gums had a bit of die back at one stage, in the 80s, during a dry period but then… I think they are as healthy as they used to be"

Referring to red gum: "There's been a die back - reduction - in number and health of trees in a lot of the more forested parts of the Marshes… from the '80s on."

"The 54 flood drowned a heap of Gum trees on Messines… a patch (where) you'd really have to say thousands of trees, definitely hundreds and big trees. Like trees that are probably, I don't know, 15/16 inches through."

"(All the plants are) pretty much here. They come and they go over the seasons and the droughts and the floods but there's nothing that I can say it used to be, or it used to be covered in such and such and now it's gone. Because everything - it's gone for a while but everything's pretty well coming back eventually."

"They're going to tell you cumbungi (has taken over) but I won't because I think it's seasonal… Other than the loss of reed… I don't think there's been too much of a loss in the biodiversity… But reed is less prevalent than it was.,, right across the board whether it's here, the northern reserve, Gum Cowal… it is trying to creep back."

"There's a very good stand of couch grass at the moment… extremely good with these good seasons."

“It's very hard not to be biased while they're current events. Like what we're seeing isn't normal for the amount of water that we have for marshes. So we are seeing less of everything because the area of flooding's less.”

Reed beds

“(The reeds) define the Macquarie Marshes.”

“We (burn them) currently… a few times since '84… (because) the Aborigines did…People burn them for fun… Just when the water was coming… Once every couple of years… three to four years I think.”

“ (Reed bed areas are) reduced in size and dependent on grazing pressure and fire... that’s for the whole Marsh… specifically for [our property] - reduced in size and I know the management things that have brought that about being flooding that's moved from - and some of it's natural movement of flooding from one area to another caused by changes in channel profile and depth, grazing management and fire. We burnt a patch of reeds on [our property] and only a small patch, not the whole lot… and the regrowth- the cattle concentrated on the short reeds and they never fully recovered to the extent that one year we put an electric fence around to exclude the cattle. It wasn't very satisfactory but it gave that patch of about 100 acres a chance to recover.”

“Yeah the fire management was for grazing to provide fresh, green feed. Fire management is critical that it be done over water. So if the reed beds are wet - saturated - when you burn, otherwise you destroy the root system. That's what happened in the northern Marsh over recent times. There have been several fires there that have burnt out the reed bed. The idea of burning them to produce feed needs to be done and controlled.”

“(Reed bed have been burnt) to provide access more than feed I think over the Marshes as a whole. They still produce the same amount of growth but it looked better. You could access it after it had been burnt.”

Loss of reed beds in Southern Marshes: “I can theorise on that. The Macquarie River at the Monkeygar Creek junction used to just come to an end virtually and flood out and reform into the Macquarie. Then Monkeygar Creek was encouraged and cut deeper till it drained a lot of that southern Marsh - down - shifted the emphasis from there down to the [Unclear 0:57:40.7] area and further downstream... it stops at the western side of the southern Marsh - was most affected because that's where - that what used to be flooded from the old Macquarie. However there used to be reed beds right out there near the road. Not in my time but right out on Thornton's country, the reed beds used to extend where they've been cropping there recently...”

“To my mind reed beds are rather sterile environment. They don't provide much habitat or foraging area for birds - you get the little reed warblers a bit but - and plenty of frogs - but as far as the larger vertebrates they don't go in them. Reducing the area of reed bed I don't think it has had on the quality but it's had an effect on the grazing productivity of the country. A lot of that's in nature reserves anyway so it doesn't apply now.”

“They're a stabilising influence. They trap the sediment… the big reed beds are nearly all on high ground - on delta. Then the river finds another way around, leaves that reed bed high and dry. After about 50 years you've got a beautiful black soil plain.”

“In the southern Marshes what used to be reed bed it's taken probably 50 years to go through that transition to a grassland of native grasses.”

“The removal of medium sized floods has impacted on the reed more than any other plant species.”

“We generally burnt here whenever there was enough of a flow in the system to wet the reed bed. So it could have been every year through the 70s… Burn when there was water on its way… They still graze there like did before but it's just grazing a lesser area.”

Cause and impacts of reed beds lost in the Southern Marshes

“Yeah, it would be a combination of everything. But definitely river regulation, I think probably had a lot of impact there. The breakaway channel probably would have gone a long way towards draining that area.”

“They're a good indication of health of the system.”

“Yeah I think it helped the bird life, I do. I think we got a lot more birds on it because there was a lot more shelter, that's probably why we're missing a few birds now because they've got nowhere to hide.”

“The water just runs through too quick… there is some big channels in there and whether the same affect where the water is just not getting outside the channel anymore… it's probably drained (too fast).”

“Well in the southern reserve it was a bit different (not just loss of medium floods)… there was banks, erosion and upstream water extraction… The loss of the reed bed in the southern reserve, without a doubt (has affected the rest of the marshes)… Less habitat, less likely to get a bird breeding event. It's reduced an area of the marshes so it's reduced to attractiveness of it for all wildlife, I suppose. The areas that are left are a lot smaller.”

Grazing productivity

“(Buck Swamp important for grazing, has become less important over time)… we virtually had to de-stock it at one time… ’96…”

“… we were (1970s) running a couple (hundred) head (of cattle) on Minna Plains… I didn’t overstock it… Burrendong Dam changed that country.”

“…In wetland country, you can probably run five cows to an acre. On dryland country, you might need four acres to run a cow”

“I think everybody's a lot more aware of the grazing pressure on the Marshes, especially the private land owners. People are a lot more conscious about not trying to over graze that country. But yeah I don’t think - at the end of the day it hasn’t changed that much, everybody's still doing what they're doing but they're just a lot more conscious of how they do it probably.”

“(the productivity of flooded country is) probably double… for grazing (compared to dry land)”

“You can't deny the fact that to go and put fat weaners straight off the mother, onto a truck and send them to a sale is a real attraction of the sale yards... they're so primed. People think they're come off an oat crop, they're that good. That's a credit to that country out there.”

“Yeah well we didn't start farming until 94 so yeah we used to run sheep on our flooded country. Yeah and then when we started in 94, in the farming side of things, we got rid of all the sheep and yeah we - yeah 90 was a big one (flood) because we had to take sheep off and put them on the neighbour's.”

“(For our property) the Couch grass meadows would be the most important for grazing followed by the reed beds for cattle because the Couch grass is high volume, low nutritive but is compensated by the high protein content of the reeds. They actually have higher protein content than Lucerne. The young, fresh reeds. So in combination they form a tremendous and productive pasture. There's been a slight swing from reed dominance to Couch grass dominance.”

“Well the dry land area is rated about four acres to a sheep. We have run cattle on (our property) at one beast to the acre which is ten sheep equivalent to the acre. So that's the difference… one cow is equivalent to 10 sheep. That's quite significant… Just as an aside- most of the holdings along the Macquarie were, prior to Burrendong Dam, were at around the seven, eight, nine ten thousand acres along the Macquarie. They were sufficient in size to provide a good income. As the flooding decreased a lot of those small places were bought up and the holdings got up to 30/40 000 acres to provide the same level of income. I know there were other economic changes and things at the same time but the average holding size around the area is probably 30/40 000 acres whereas along the Macquarie or the Marshes they're down to 10 or 12 000 acres. So much more productive.”

“That’s easy. (The productivity of frequently flooded areas is) multiplied by four, compared to the rainfall (reliant areas).”

“Reed and couch are the important parts of grazing. This is challenged because it's reduced.”

Grasses critical to livelihood

“Couch Grass… It needs a flooding every couple of years, doesn't it, to keep going… Yeah, there seems to be a lot of curly windmill grass out there during the summer time on the high country and it's really thick along the road there now. So I'd put that down as well.”

“We call it Gum Grass, I don’t know Millet Grass. Couch, Clover… Crowfoot… (Couch) comes and goes. Clover and crowfoot during the winter, it's a winter herbage and then- Umbrella grass, blow away grass, plenty of it this year… Clover and Crowfoot and that in the winter and then your Gum Grass all the rest of summer.”

“Not so much barley grass anymore… No barley grass has gone probably, it's probably one that's disappeared for a while… It used to be real bad and we changed our shearing because of barley grass when we had sheep… we shifted our shearing (from May/June) until the September so we shore all our lambs and I remember going around the paddock with dogs and catching lambs and pulling grass seeds out of their eyes… Carrying a pair of tweezers and blue stain, a lot of people reckoned we were cruel but blue stain was one of the best we found, you didn't have to treat them again. It was easy because it used to leave a little blue stain in the corner of their eyes so you knew you'd done them. You used to cut the blue stains, cuts brown flesh and it used to get any scum on the sheep's eye. Just tobacco tin full of blue stain powder and sprinkle a little bit in. It was a gross job.”

“Wetland species first - they're the Couch grass reeds. (They come up in) spring time. Well probably the most productive (dryland species) is [Unclear 1:16:35.0], an introduced species. Saltbush - various saltbush species. You want a list of them: dry land saltbush, prickly salt bush, creeping salt bush... all of the above. Yeah the grass component of the Curly Mitchell no. Curly Windmill grass and Windmill grass are probably important. Dry land grasses. Some Mitchell grass but limited ...”

“Couch... grows spring/summer… Well, if they're not good for grazing, we're not interested… Mitchell grass, umbrella grass… It's a full picture. Cattle in a paddock full of couch won't do very well. Cattle in a paddock full of couch with reed, cumbungi, nardoo, some gum grass, umbrella grass… Fantastic… Any monoculture isn't productive for grazing of livestock… Just like us, we can’t survive on pizza alone.”

Cropping of previously grazed land

Some participants say that changes in water availability has put pressure on to diversify, most have cropped small areas at some time to grow forage feed.

“We've got 600 acres of country that we can use for cultivation. We usually grow a fodder crop, they're oats… Last few years, we haven't worried about it because of the drought, we decreased our cattle numbers and we haven't had enough weaners on, for example, to economically justify I suppose… It's probably more of a value adding to our weaners I suppose. Instead of setting our weaners straight off the cow, we might be able to take them off the cow, put them on there, get them to a certain weight that the feed lot might find them attractive sort of thing. So that's what we've used it for. We haven't really used it as substitute to substitute the wetland area… (we) started growing oats during the early 80s… Because (we) never had the gear to do it until the early 80s… Late 70s, early 80s that would have started to happen… If the water scenario was as it used to be that wouldn't have happened.”

“During the floods yeah, we got rid of the sheep in ‘94 and started farming then. We just - at the bottom of the sheep prices probably and it was an economic decision, not a preference decision, it was an economic decision… Had nothing to do with the country as a flood country or anything.”

“We - in early 1990s we set up a small irrigation block and that is all. It was cheaper to increase the productivity that way than buying more land. That was the main reason apart from the fact the land wasn't available. It was on dry land country… country that got flooded twice in 40-odd years - 50 years. Reduction in the profitability of sheep was probably the driver… virtually no income from sheep. We had to make the cattle more productive and that's - a number of things happened at the same time. We changed from a Devon to an Angus herd and started a pretty intensive upgrading of the herd. The combined - the growing out of the steers - to feed a steer weight - in the shortest time possible. We are turning off feed of steers at 12/13 months now whereas we used to turn them off at 18/20 months. That's partly genetic and partly fodder production.”

“On a small scale we've moved to cropping during the 80s from loss of reliability of the flooding… forage cropping for grazing.”

Recreation/activities associated with floods/ visitors during floods/ depth of water

Some participants engaged in recreation following floods in the Marshes. Stories of swimming and boating come from a time when they were children or when they had small children in their family.

“Coming out of the 10 years of drought, I think we did it every other weekend, we'd go for canoeing trip with our neighbours, family, visitors and it was like being in a whole new world wasn't it? …the place is alive. Like you might not necessarily have been out in that country for six months because it is wet and hard to access but you've got to get out there and get the cattle in.”

“Yeah when I was at school there was at least one family had lease blocks on the marshes. Yeah, they often had stories about coming over with their family, with horses and swimming, getting their cattle together - we were in awe of the stories coming back like how could there be such a land as this? Macquarie Marshes where you swim all day and on your horse.”

“I always say I want to put a canoe into Marthaguy and go for a paddle down there… So I wouldn’t mind doing that, I'm going to do it one day, get off my butt and do it”

“I have been (swimming) a couple of times… on the Buckiinguy Creek… Yeah, a bit of recreation. I think (Dad) took the boat down there one time… Buckiinguy Creek was at least a metre and a half deep”

“We did that one Christmas when (friends) were up here for Christmas… Years and years ago… We took the boat down on (Buckiinguy Creek)… It was just a little tinny.”

“We used to swim in the Gum Cowal as children, kids still do it now… we've skied on it just for a laugh and I had the kids on a knee board when they were little babies, just for fun... we've had different people canoe up and down it.”

“I guess you call it the visual value, what's the right word for that? (Aesthetics-Int.)…Yeah, I guess. That's pretty important actually. I'd rate that as very important… there's a lot of value in that.”

“We didn’t do anything… differently… We didn't think oh it's a flood come on we better go and do such and such… You go into town, you just get your supplies and then you sit, wait and see and then hopefully it's usually gone by the time you run out… Or you just get the chopper in. Even in 54 I remember them lopping food supplies out of the old DC3 or whatever, they busted more stuff than anything else. (We were cut off for) six months.”

“No, no, the best memories of boating was starting off at Oxley, putting a flat bottom boat in the river and coming right through to the Monkeygar and on to the [Unclear 1:34:31.5] Road.I did that with Keith Simpson who's probably 80 at the time. Some of that entailed getting out of the boat and dragging it because we ran out of water. It would have been ['88]. It was on Falling River and it was probably nine foot Oxley - on the Oxley gauge for what that's worth. Twelve foot's a flood at the Oxley so it was that far down from the top of the banks. So it might have been 10 foot but year? Might have been mid-'80s I think. Yeah I think so. Then another time my daughter and I - put the boat in on the [Unclear 1:35:57.2] Road and came down through the ... Marsh and down the Monkeygar to the ... Warren Bridge. That was hard work because the channels disappear and you've got the wall of reeds in front of you and you walk through and pull the boat and push the boat. Once you get it up on top of the reeds it skids along and skates along fairly well. You wouldn't do it with a - and that's with oars without a motor. Other memorable ones is going down from Maxwelton down, following the old Macquarie down into Monkeygar during bird breeding events and really spectacular. Huge numbers of the nesting Ibis and Egrets. Following the '90 flood - it was one of those. Lots of times and I've done it numerous times and (others) have done it in the canoe. The last time I did it it was in the canoe… four years ago. A lot easier in a canoe than in a boat. That's probably the best - that and riding a horse... you find an excuse to go for a ride.”

“We've camped on the river. We had a caravan. We were taking the caravan down and camped on the river bank. On (our property). Just a mile from home. We've had lots of picnics - work, families, extended family, picnics on the river bank. Sometimes in the winter time you find a good sheltered spot. Mainly the reason for it was just to be out in the open and on the river without any intents of catching fish or any water activity. When the kids were little, when they had friends they'd be in the river of course getting muddy.”

”Another activity was pig chasing. Great fun. Going out with a rifle and hunting pigs. Yeah. Lots of visitors from Sydney and other places - friends that had come up and that was their main purpose of the visit was to chase pigs. Occasionally I'd go out with them. I'd enjoy it too.”

Regarding visitors during floods: “ We try and encourage as many people as possible… Oh yeah, absolutely… when I was at school there was at least one family had lease blocks on the marshes. Yeah, they often had stories about coming over with their family, with horses and swimming, getting their cattle together and it was - we were in awe of the stories coming back like how could there be such a land as this? Macquarie Marshes where you swim all day and on your horse."

"We (go into the water) every day… Yesterday. The kids have a couple of little kayaks and when their school mates get dropped off here in the afternoon that'll be the first place they want to go. (Some friends) were dropped off here from school last week and so there was four kids in the canoe for couple of hours having a really great time…"

Mustering during the flood

"Yeah, it's pretty awesome. I've only been on the horse once or twice. No, it's definitely pretty awesome… you flush (birds) out. But it's just nice getting wet, I suppose… it is nice and just seeing the vegetation cover. It's really good. You see a few fish out in the flood plain, I suppose."

"… before motorbikes, they did it all on horses."

"We were on horses... we didn't muck around on them. You were pleased to get off them… Sometimes we used to ride from (home) out to the river… I was out in the freezing water…"

"In a big flood the cattle aren't in the reeds; they're out on the edge of the flood country. They walk out into it to feed so mustering in times of flood is quite simple really. You just gather them up from the edge. Other times, when they're spread out and there's only small areas of flooding, the cattle's scattered. Every bit of water there's a few and they take shelter in the reeds. It's like going through a tunnel particularly when the reeds are 15/16 foot high. You're riding through and it's - the cattle have got deep pads through the reeds of maybe a foot or fifteen inches deeper than the actual reed bed. You've just got to stay in those tracks and the horse has got to follow through. If it gets out of those tracks he gets reeds tangled up in his legs and he goes down. So an experienced horse will just stay in the track, put his head down and push through. The reeds will part above you - you've got to hold a hand up in front of your face save you don't get clocked in the eye. When you find cattle in that situation you've just got to follow them, stay with them until they come out where you can do something because you can't get around in front of them. You've got to approach the job in a way that you know you can drive them out rather than drive them in. On a cloudy day very easy to lose your sense of direction because you can't pick up any landmarks around. So you go round in a circle two or three times and you're completely bushed. Very hot and humid in the summertime, yes. Plenty of flies. Special mention of riding out in flood water in the winter time when there's frost on the ground. Very cold feet. Very cold, wet feet and legs. Depends on the size of the paddocks and the job that has to be done but probably five or six people on horses if you're handling a big mob in a big area. With the cattle under good control - they're not wild, they're not attempting to get away from you - you can do it with two or three."

"Some other properties I know, during the drought, they could do all their mustering on a motor bike and then floods came and that's where the horses come back into it. You've got to swim channels, you got to go through bog."

"It's better than when it's dry. Is about all I can say... Well it's quite spectacular really. You're swimming rivers, you're going through channels, the place… It does make it more difficult to handle live stocking… No, but the place is alive. Like you might not necessarily have been out in that country for six months because it is wet and hard to access but you've got to get out there and get the cattle in. So you might see a heap of swans fly up off the river and the kids are pretty excited about what they see out there.

Yeah, it is a good time. Like you can see the country's productive and the animals have done well, it is a nice time."

Climate risk/ adaptation

"(Rainfall or drought frequency) seem to be a bit more extreme… I don't think it's anything new about the changes but they're probably a little bit more extreme… (will increased temperatures effect the Marshes?) the answer would be yes. It'll increase temperatures, going to create more evaporation. Being a shallow flat type flooding environment, evaporation is going to increase. You would have to reduce grazing pressure I suppose. But the key point that needs to be put there is you have no control over native animal grazing pressure. When it gets dry, the roos will move in, move there by thousands. I think that's a key point, grazing pressure is just not us. I'm not saying grazing pressure is all bad but I'm just saying that grazing pressure when you talk about that, it needs to be noted that we can't control what the kangaroos do… During those dry times, they just hammer it… They move in there by the thousands."

"Yeah, we did. Well, that's right we have (already adapted to dry periods). When you talk about how to manage marshes, it comes back to - the biggest factor to that is water. How far this impacts- what I mean by that is being able to deliver more water per day than what the dam can basically do. Well, that would be the thing that could counter-balance potential environmental changes. I'm a bit of a climate change cynic I suppose. Sorry, I'm not going to jump on the climate change bandwagon. So I guess really that's a pretty key point. Water sharing plans are a major factor in this. The point I raised that I raised before is supplementary pumping. To me that has a major impact during times of dry."

"I have to answer yes to that because I've organised myself to be prepared. If it doesn't happen I won't mind… I'll do what [my son's] done and buy more country. I see the only way you can cope with that sort of a change in your environment is to expand so that you've got a bigger base to maintain a similar level of production."

"Increased risk of fire is probably the biggest thing. If you've got a fire you've previously had a feed - you've had growth. So they tell us that we're going to get increasing intensity in rain events or climatic events as in the storm they've just had over in the United States."

"The Marshes can cope with that I think. That's a tremendously resilient environment. You add water and you've got it. There'll be a reduction in long term - 100 years - there'll be an increasing demand on the water and the allocation of water to the environment that we have now and the Macquarie Valley might be at risk. That, I see, is the biggest threat to the Marshes if that environmental water is reduced through human demand. You can't do much about that."

"Yeah (the Marshes are) managed almost to the nth degree now. If we get those major climatic events that we might get, well the Marshes are going to love it. The big rain events, that's what makes it. The dry times, well there'll be some losses but they'll still be there and that was probably one of my first observations about the Marshes was how quickly it responded when you added water. You thought the place was just a dust bowl; there's virtually nothing there. A few stumps of reeds. Add water and within a week or ten days you had feed. Wonderful. Oh that was in the '60s. After that extended period of no-flows rivers dried up... I had faith in it ever after that. Doesn't matter how dry it got you give it the water and it'll respond and it'll recover very quickly. There's been a lot of talk about a deterioration but there has been in certain areas but the best of the wetland is still as good as it ever was I think."

"I don't say it concerns me but that I'm aware of as far as managing the Marshes is that it's a natural environment, and natural environments change and move. If you looked at the Marshes over the last 1000 years or 2000 years they wouldn't have been where they are now. If the management tries to limit that change by restricting the Marshes to the nature reserves and curtailing any natural change that would take it somewhere else it's no longer a natural environment. You've got a managed environment that you have to manage and you can't really say that it's natural any longer. It's controlled."

"I do accept the theory of climate change but I don't think the impact it's going to have on our business or the marshes is anywhere near the impact river regulation has had. Remembering that the marsh is - the growth period is during the spring so an increase in temperature will help that but an increase in temperature may also mean a decrease in available water. So there'll be positives and negatives."

"We have adapted but there's a lot of ways. Well if you looked at the drought, with modern freight… Road transport… Increasing the fertility of cattle so they're calving over a shorter period so you can get rid of them sooner. Improving growth rate so they can reach their… Target weights… In a short time... By fine tuning our cattle it gives us more options if there is dry coming, if we're not getting as much water as we could have."

"The marshes will always be here. It's just… Well as you say, it won't cope… How will it cope? More water. That's how it will cope… You could read into that question a lot of things couldn't you? We should be allowed to have more water. So to manage to cope? Yeah, more water for the environment. I think if you start increased regulation of where you can put the water the area as a whole will suffer because one of the unique things about the marshes to date has been the lack of control of water entering the system as a whole... Because every part's unique. It'll come down to individual's decisions and that may be the wrong decision for the marshes as whole. So I think increased regulation will be to the detriment of the marshes."

Referring to whether increased temps will affect the Marshes: "It probably will if it does happen, I'm not a believer… It has to be a major change in temperature to change it I think and I don't think that's going to happen… This one or two degree in a hundred years isn't going to make much difference to it… (Compared to) what we got now." Referring to adaptation: "I don't know, cross that bridge when we get there. You deal with it and see what's left I suppose… Take a teaspoon and smack it hard enough… Build a bridge and get over it."

3.6.4. Conclusions

A number of patterns emerged from the interviews of changes observed by landholders in the occurrence of animals across time. These included a decline in both high numbers of mosquitoes from the 1970s and black butterflies from the 1980s until the flooding in 2010 (Figure 56). Dragonflies have not been observed in high numbers since the late 1980s (Figure 56). The pattern is similar for snakes and frogs which were observed to decline in the 1980s, but started to improve 30 years later in the 2010 flooding . In contrast turtles appear less abundant now, possibly due to predation on their eggs by feral cats and foxes (Figure 56).

Waterbird breeding was observed to decline from the 1980s, but swans were abundant on lagoons around 2000 (Figure 57). The bustard is no longer seen in the Marshes (Figure 56). Cod, catfish, and yellow belly were prevalent until the mid-1970s, but declines in the mid-1980s coinciding with the arrival of carp and gambusia (Figure 57).

In terms of plants the main changes observed were the loss of reeds in the 1980s and their re-appearance in some parts in the recent wet years. Wetland plants were observed to still occur, but just less often due to reduced flooding (Figure 57).

Landholders observed that water is moving through the system faster than in the past and thought this was due to dry conditions and loss of vegetation cover. Associated with this was a perception that erosion is increasing. They observed good water quality generally, without any issues such as blackwater and blue-green algae. Many landholders could identify the source of floodwater based on its colour.

Figure 56: Observations of animals (invertebrates, snakes, frogs and turtles) over time. Blue line depicts water flows reaching the Macquarie Marshes.

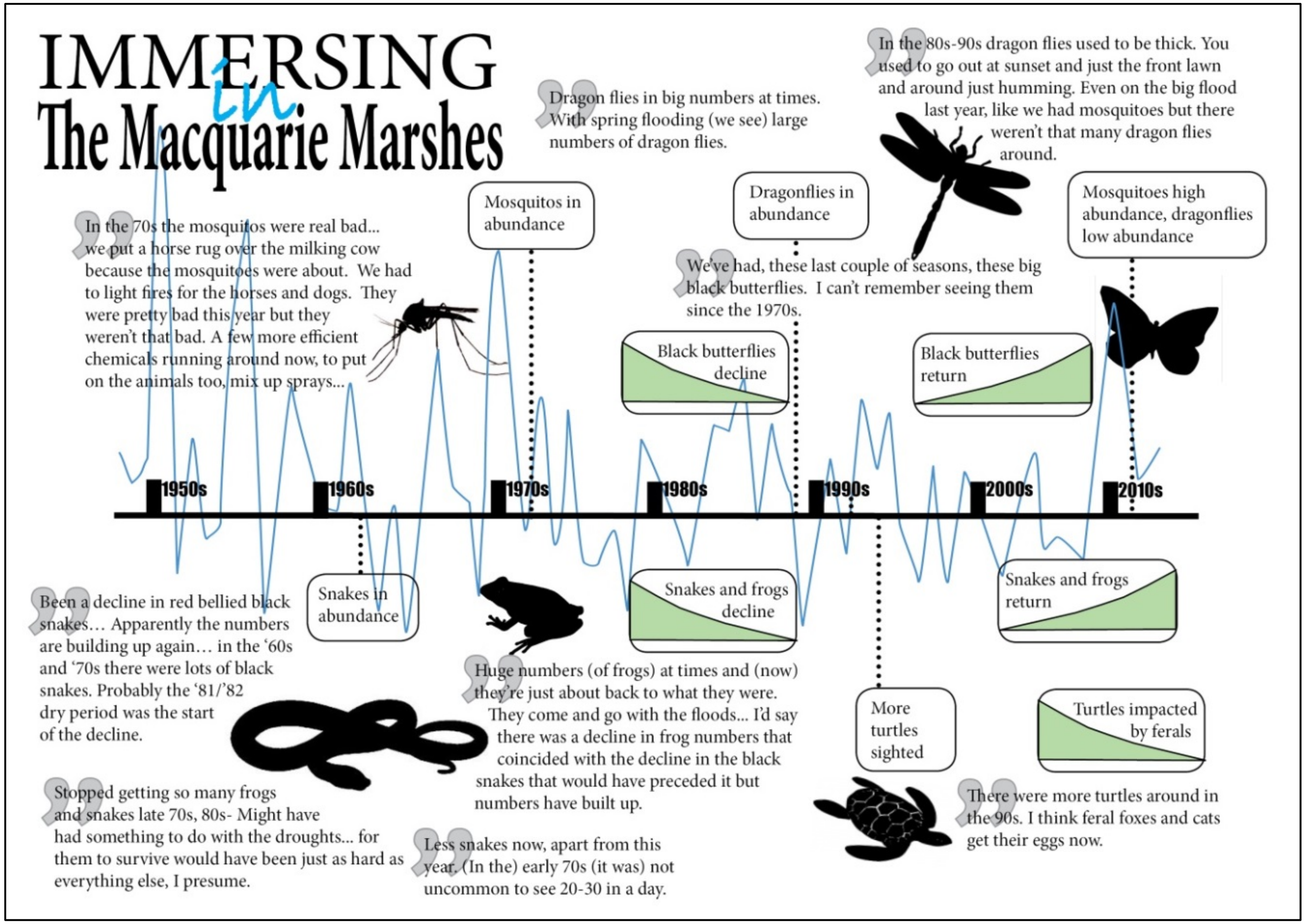


Figure 57: Observations of animals (waterbirds and fish) over time. Blue line depicts water flows reaching the Macquarie Marshes.

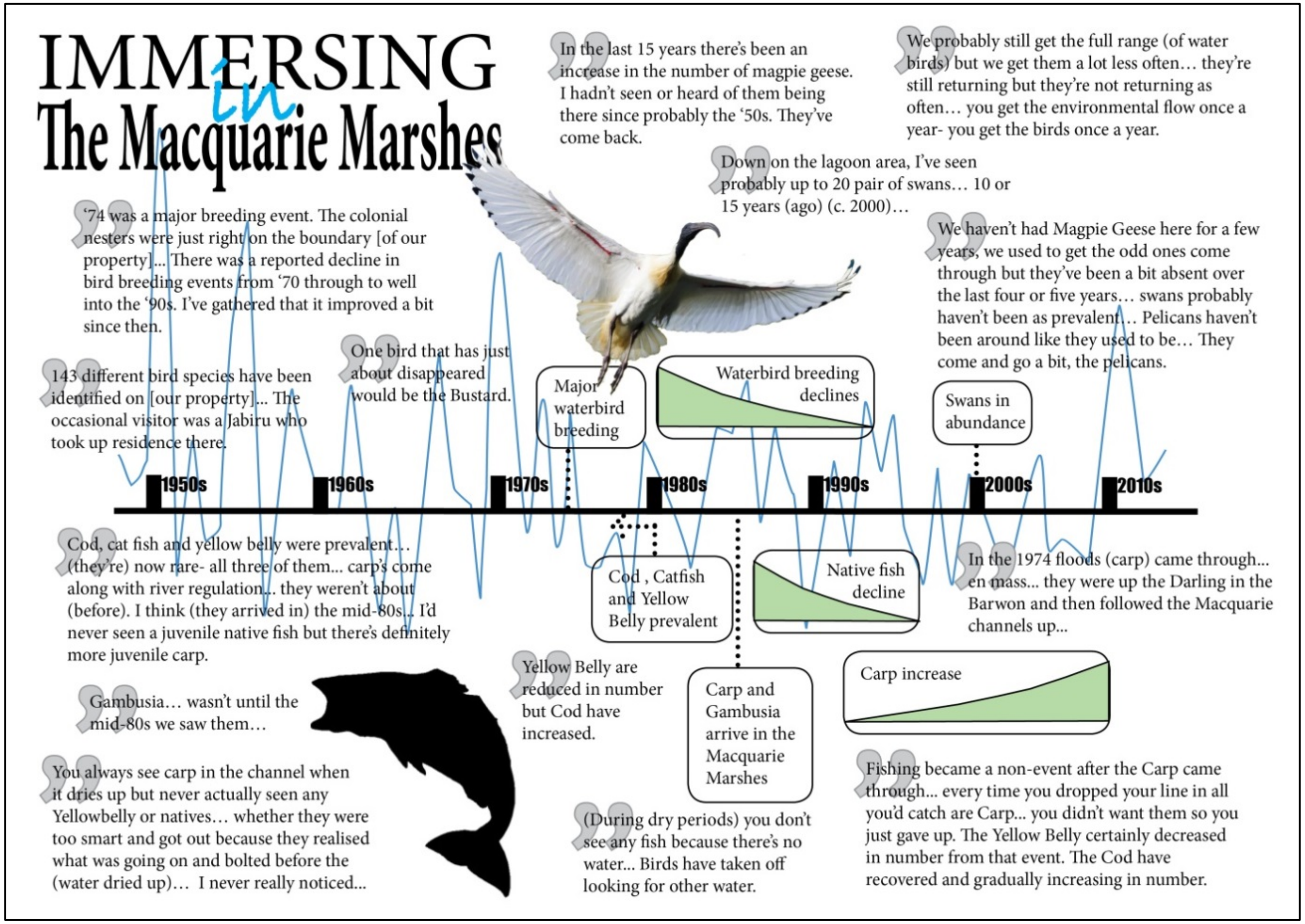
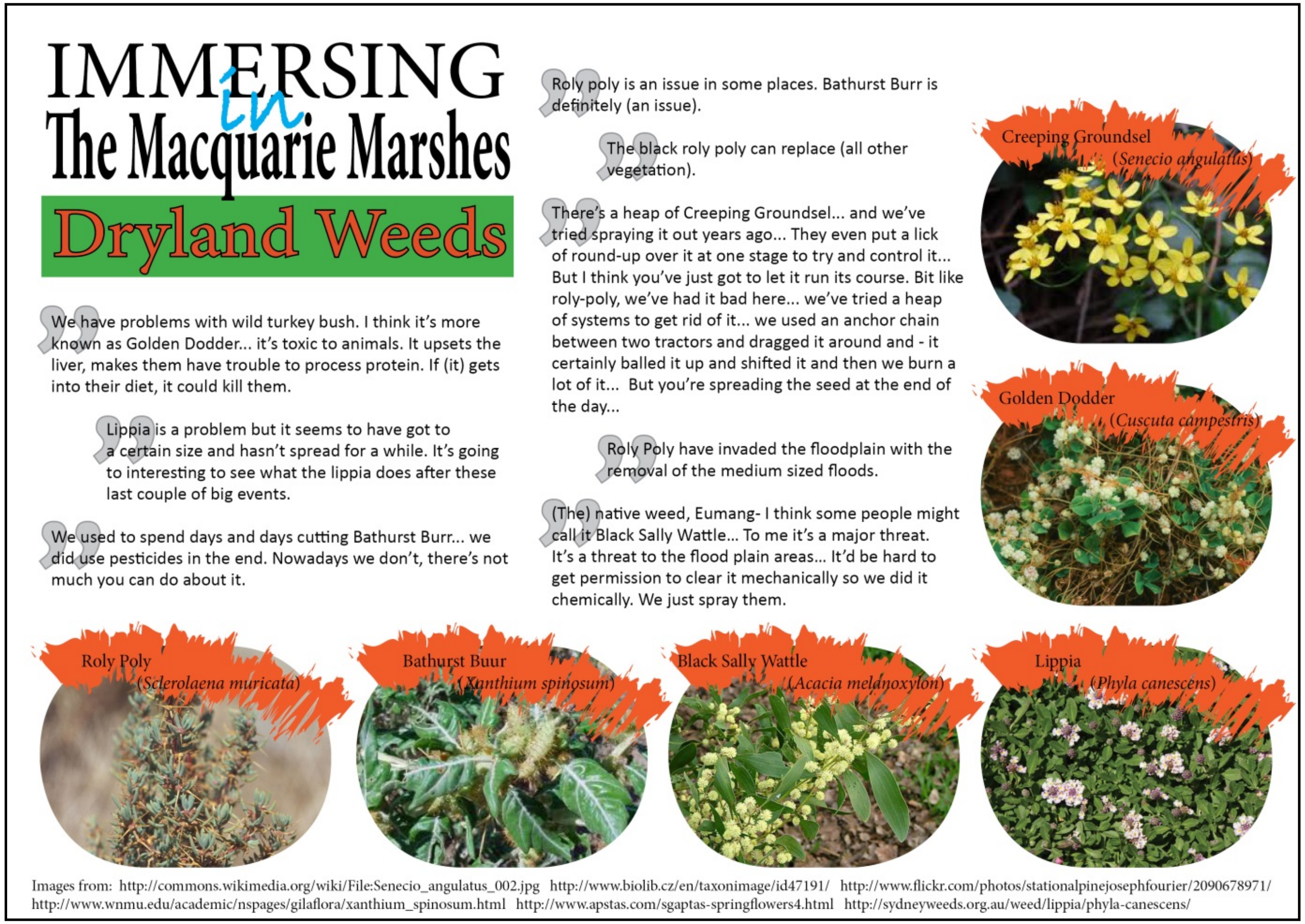


Figure 58: Observations of dryland weeds over time.



4. Final Discussion

The ability to adapt in a changing environment is a vital aptitude for effective management of the ecosystems. A strategic adaptive management framework (SAM) can be articulated and developed to guide current and future management and ensure learning by doing. This requires the explicit development of a hierarchy of objectives and implementation of management that focuses on priority objectives over time. Improving the understanding of cause and effect and scientific tools to ensure that this process is effective is critical. Such a framework allows managers and the community to have some confidence that management is underway, aimed at achieving explicit goals. Without such a clear framework, it is difficult to track whether management is effective or not or if it is achieving its goals.

Inability to recognise deteriorating conditions of ecosystems, notably beyond resilience tipping points, and adapt accordingly, will ultimately result in the failure in obtaining management objectives. Adaptive management aims to provide a formal, systematic, and rigorous framework to gain knowledge relating to the management of a system from previous outcomes of management actions. Thus, management adapts and continuously improves, as new information is collected. This includes dealing with climate change and providing mechanisms for dealing with it adaptively. Adaptive management requires a continuous synthesis of existing knowledge, exploration of alternative management actions, and making explicit forecasts of ecological assets based on constructed models. To facilitate this framework, management actions and monitoring programs should establish tangible feedback loops relating to the outcomes of management choices. Critically, future management actions and objectives would be adjusted accordingly.

4.1. Integration within the SAM framework

This project aimed to consolidate and add scientific knowledge required for the adaptive management of the Macquarie Marshes. Specifically, we aimed to integrate climate change adaptation strategies across different management scales and responsibilities. Adaptation strategies are vital, as climate change will inevitably affect conservation objectives, policies, and legislation, all of which will influence the availability of water, the key ecological driver of the system (Herron et al., 2002, CSIRO, 2008a). Following the framework for strategic adaptive management (Kingsford et al. 2011), this project interacted and added to the four main steps of the generic management framework (Figure 59).

Both review of scientific information (3.1) and review of local knowledge (3.6) provided valuable data required for developing management objectives, thresholds for the ecosystem, and responses to drivers, including climate change. These helped clarify and reinforced the key attributes of the ecosystem (biophysical, cultural, and services) that characterised the intrinsic nature of the Macquarie Marshes. Recording long-term local knowledge information of past flooding patterns and responses of biota can significantly improve our conceptual models of how the system works and how it will respond to projected climate changes. Once recognized, key attributes then form the basis for establishing management objectives.

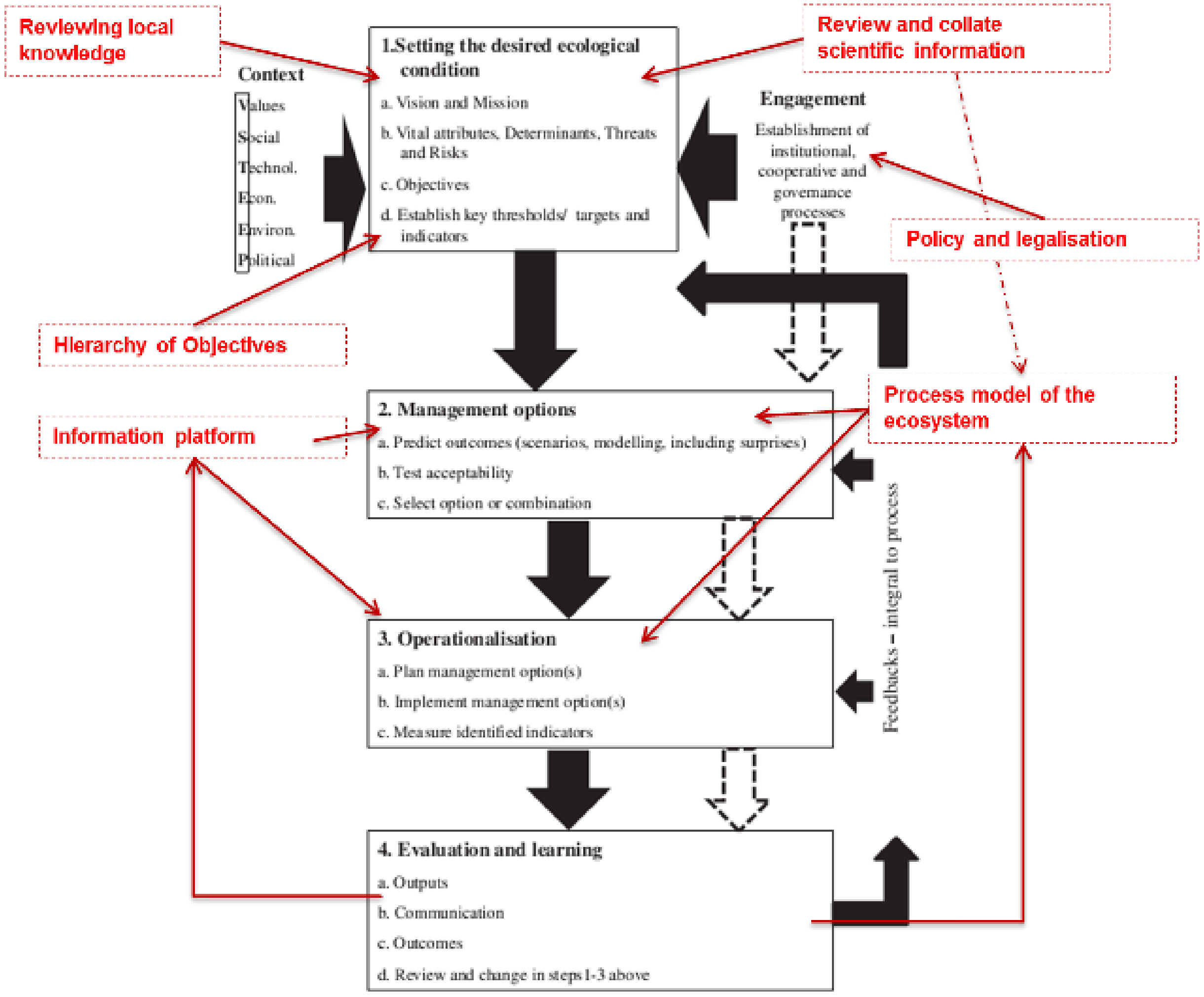
This project further integrated climate change adaptation objectives within the adaptive management framework, as part of the objectives hierarchy (3.2), currently under development within the NSW Office of Environment and Heritage (OEH, 2012b). This project provides opportunities for identifying how climate change adaptations may be incorporated within an objectives hierarchy. In many ways, incorporation of climate change objectives within this hierarchy is simply an extension of how objectives and processes are established to deal with the effects of water resource development on the ecosystem. True adaptation to climate change will require coordinated institutional and policy change which may be effected through the SAM approach.

Critically, SAM depends on constraints and opportunities, which can be provided by legislation and policy as well as drivers in ecosystems. Many different policies and legislative instruments affect the management of wetland ecosystems, operating at different spatial scales, reflecting different institutions and their focus. These policies and legislative responsibilities operate at different levels (Figure 59) but are particularly important in determining the achievability of objectives. It is clear that despite the many different policies and legislative instruments governing the Macquarie Marshes and its water management, the development of a SAM approach is consistent across all types of legislation. Thus, governance, planning and policy driven by the different legislative planning requires assessment of alignment to further drive the proposed climate adaptation approach. This project reviews, details objective settings, and legislative responsibilities. More so, the project assesses alignment with the adaptive management framework and identifies opportunities to incorporate climate adaptation into existing management plans (3.4). There was considerable opportunity to develop and build on the current progress by OEH in the SAM approach in the Macquarie Marshes, providing a more integrated and effective way of managing the different legislative and institutional responsibilities affecting the management of the Macquarie Marshes.

Understanding how a system works and the impacts of drivers on stressors and ecosystem responses remains a critical step (Figure 59), allowing for improved predictions from modelling. Building a system model of the ecosystem is critical as it facilitates testing alternative management options against our understanding of the ecosystem. Providing an explicit model should include key components of the ecosystem. This project developed a quantitative process model detailing the different ecological states and the main drivers of change (3.3). The complexity of the process model was highly dependable on the availability of ecological and physical information. Continuous and long term monitoring of two key attributes of the Macquarie Marshes (i.e., colonial waterbird breeding and vegetation communities) along with corresponding flow and inundation patterns enabled the development of a relatively robust process model for the ecosystem. As exemplified here, developing such a model is critical in realising opportunities for adaptation and prediction for management of the Macquarie Marshes within the framework. .

A critical constraint on adaptation is access to scientific information for adaptation management. This project also developed an information platform that could assist managers (and the public) in calling up of data on biota, ecological processes, and a modelling capacity into a spatiotemporal interface (3.5). Providing an information platform amassing all available information relating the system can significantly improve evaluation and learning, a critical component of adaptive management. For adaptive management to succeed, management practices require constant feedback loops from data to planning. As more information is gathered and incorporated into the information platform, models and past decisions can be reviewed, adapted, and optimised for delivering greater certainty in achieving desired management outcomes.

Figure 59: integration of the project outcomes within the strategic adaptive management framework.



4.2. Ensuring successful implementation

The successful implementation of SAM in any ecosystem takes time and requires good engagement by all stakeholders to be successful. Once established it can assist with the tracking of management actions and their effects as well as the condition of the ecosystem. Depending on the selected indicators, monitoring an ecosystem sufficiently to obtain cause-and-effect relationships requires considerable resources. These indicators need to be linked to the objectives hierarchy, representing the objectives for the system. Identifying designs and monitoring strategies that offer the best cost effective trade-offs by using decision analysis can assist. A well-designed monitoring program should strive to track the response of several indicators simultaneously. Such an approach can increase resource efficiency, provide an evaluation of the ecosystem as a whole, and increasing the likelihood of identifying thresholds of potential concern earlier. Developing cheaper measurement techniques, such as long-term camera monitoring, providing reliable information can provide additional resource effectiveness. Lastly, identifying cost-sharing partnerships within both government and academic institutions can prove a cost-effective method of utilising expertise. The ability to maintain continuity of funding despite political and institutional changes is critical. Establishing realistic expectations for the framework is likely to require several adaptive cycles. The complexities of the system and the natural stochasticity can influence the rate of learning as well as the number and extent of management alternatives.

The evaluation and learning phase in the adaptive management plan is designed to review results of the processes with the aim of adjusting models, monitoring, goals, and management. Designing powerful experiments testing management actions can speed up the learning process, prepare management when faced with novel uncertainties, and prevent critical large-scale mistakes. The considerable spatial and temporal environmental variability of the Macquarie Marshes and long-term flooding cycles demand designing robust quantitative sampling designs, accounting for the inherent high spatiotemporal variability. Identifying indicators that respond quickly to change can increase confidence in constructed ecosystem models. Designing experimental approaches should be instigated focusing on robust quantitative methods to assess and compare alternative management alternatives. As more information is gathered, logistics of storage and sharing should be formalised by developing an explicit plan relating to data-use and partners.

4.2.1. Value of steering committee

Forming a steering committee made of high-level stakeholders and experts can significantly increase the likelihood of success and bolster the potential impact of any project. Committee members provided valuable guidance on key issues, objectives, and approaches. In this project, we formed a strategically targeted committee from all the major agencies involved in land and water management for conservation (see 4.7, Table 1). During the course of the project, we held periodic meetings with steering committee members. During the course of the project, we held periodic meetings with the project's steering committee to provide advice on direction and review key documents produced from this project.

The Steering committee provided valuable advice on additional data sets that should be included in developed data platform. Where needed, members arranged for sharing of data sets. Given steering committee's experience and expertise, members were particularly useful in suggesting key drivers of ecosystem change that should be reviewed, considered, and incorporated into both data platform and process models (see 3.3).

This project aimed to integrate climate change adaptation objectives within a presently developing objective hierarchy within the NSW Office of Environment and Heritage (OEH, 2012b). In order to ensure relevance and likelihood of integration, key OEH developers of the objectives hierarchy formed part of the project's steering committee and provided constructive comments and relevant information on developing drafts.

Utilising the management and scientific experience in the Macquarie Marshes was vital for successfully constructing ecological cause-and-effect model of the system. Steering committee members were key participants in the workshop as part of this project's effort to elicited cause and effect models for alternative climate change and management scenarios. Members helped conceptualise ecological assets and identify a list of priorities. Members "on the ground" management experience, we were able to identify the main drivers of the system and successfully apply data-driven ecological models of the ecosystem. Members also provided comments on the applicability of a process model approach.

Our ability to identify alignment, potential conflicts and opportunity for incorporating climate change adaptation policies into the adaptive management framework across the entire range of different scales (wetland, catchment, basin, jurisdictional, national, international) was reliant on establishing a thorough understanding of relevant legislation and planning policies. This was ensured by including steering committee members involving all the major agencies in environmental flow reform. They provided valuable input into the development of the part of the report examining the role of SAM across different policy and legislative drivers.

A key objective of this project was to develop an information platform that would allow access to key scientific information, and modelling for climate adaptation and management. Applicability and usability are both critical components of any interactive object. Steering committee members were used as a focus group to maximising usability through an iterative process in which we progressively refined early stages of design and functionality. As particular members were our target users for the final product, ensuring they were content with applying the data platform in the future was imperative for the success of this objective.

Recording long-term local knowledge of past flooding patterns and ecological history of the Macquarie Marshes required we interview both residents and government employees who have intricate knowledge with the ecosystem. Several members of the steering committee had such knowledge and took part as interviewees. Steering committee members were also able to provide past surveys conducted in the region as a useful comparison and a reference to build on. Discussion during meetings with the steering committee provided helpful guidance on how to frame the interview and suggestions on specific questions.

5. GAPS AND FUTURE RESEARCH DIRECTIONS

5.1. Adaptive ecosystem management

The main goal for management of the Macquarie Marshes is to achieve a desired state, encapsulated in a targeted vision statement. This incorporates ecological values or assets and supporting processes. Quantitative analysis built on well-planned monitoring designs will enable constructing more sophisticated ecosystem response models of flooding events. Because the wetland system potentially moves between states, represented by changes to flow regimes and other factors, ecosystem management should focus on understanding these processes and the rapidity of movement to states that are undesirable. This requires identifying some explicit indicators that most effectively and efficiently provide the requisite information allowing measurement of progress toward an articulated desired state. There is a need to keep developing the hierarchy of objectives to provide direction and increasingly incorporate further objectives that can be at different scales for the ecosystems and also institutions. Further, improved ecological models linking ecosystem succession and management can prove useful tools for describing and predicting community change. Such models have the ability to promote understanding and enhance predictive capabilities of ecosystem, change as a response to climate change and management intervention. Ultimately, such a framework depends on the level of adoption by managers and its usefulness.

5.2. Costs and benefits of different management options

There are always costs and benefits of management, including doing nothing. These manifest along temporal and spatial dimensions. For example, there may be additional benefits of ‘storing’ environmental flows to produce a large flood, instead of releasing environmental flows annually, particularly in systems adapted to boom and bust cycles (Kingsford and Auld, 2005a). These need to be assessed using available models and scenarios. There are also additional costs due to ecosystem monitoring and model development and pursuit of different management options. Comparing the potential costs associated with conventional management and assessing the potential long-term cost from making ineffective decisions may highlight the benefits of adaptive management. It is useful to incorporate potential long and short-term costs in assessing values of management.

5.3. Predictive capacity

Improving models may decrease uncertainty of predictions. Developing a predictive capacity of ecosystem responses, through various indicators, to flooding events can support management options to identify and provide flow regime that assist in reaching the desired state. Fostering predictive capacities rely on fine-scale spatial data of the system. For the Macquarie Marshes, improving hydrological modelling taking into account spatial complexities and connectivity are vital. Although the configuration of spatially separated sections of the protected area adds complexity to management, it can also allow flexibility in identifying unique management objectives for each and identify efficient allocation of resources. Understanding how different indicators respond to the spatial and temporal patterns of flooding is critical and can help ensure that all ecosystems components are considered in management. This will also include testing the efficacy of current surrogates used for management (i.e. vegetation, breeding of colonial waterbirds).

5.4. Passive vs. active management

Adaptive management utilises management interventions in a learning process. A distinction between two approaches within the adaptive management framework is the degree to which decision makers anticipate the influence of management on learning, and the degree to which management is used proactively to accelerate the rate of learning. Passive management focuses on achieving management objectives based on formulated models, with learning and revision of models as additional information is collated. Contrastingly, active management involves active pursuit of knowledge through experimental management. Both active and passive adaptive management utilise management interventions in a learning process. The key distinction between the two approaches is the degree to which management is used proactively to accelerate the rate of learning. Indeed a passive approach may be less risky than an active one, but experimenting with key indicators where several alternative management choices are compared may allow more reliable interpretation of results, although this is not achievable at a large scale where there are issues of adequate replication (Kingsford et al., 2011a). There are some opportunities to test effect of different management options in the Macquarie Marshes by releasing environmental flows into different areas (water management areas).

5.5. Climate adaptation

Climate adaptation and management offers opportunities to defray the ecological impacts of anthropogenic climate change. For the Macquarie Marshes, these are already clearly identified in relation to the impacts of water resource development (Jenkins et al., 2011). The key climate change adaptation strategy is to provide adequate environmental water allocation aimed at reducing the short (1-3 years) and moderate (4-7 years) inter flood intervals, assuming that there will be a drying pattern as indicated by available evidence. Doing so will not only buffer the ecosystem against projected, long-term, climate change but will also slow the current state of declining ecosystem health due to river regulation. For such an adaptation to succeed, changes are required within the social institutions. Namely, society must increase the value it places on the natural environment of the Macquarie Marshes so that it chooses to restore the short to moderate inter flood intervals. Actual implementation can be effected through environmental water management among years and potentially altering rules within the current water sharing plan to specify shorter durations for the inter flood intervals. Applying a strategic adaptive management plan that builds on identified and proposed solutions to adaptation limits in governance developed in this project (3.4) should assist in identifying successful adaptation to climate change. There are increasing opportunities with more sophisticated models to explore the benefits of these adaptations on environmental flow releases. Improving hydrological modelling capacity and testing ecological responses to increased allocations of environmental flows will enhance development of management strategies. This will require continued prioritisation of ongoing quantitative monitoring, aimed at assessing the outcomes of taken management actions.

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7. Appendices

7.1. Appendices for section 3.3.1, expert elicitation

7.1.1. List of participants

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Other experts in management and science of the Macquarie Marshes

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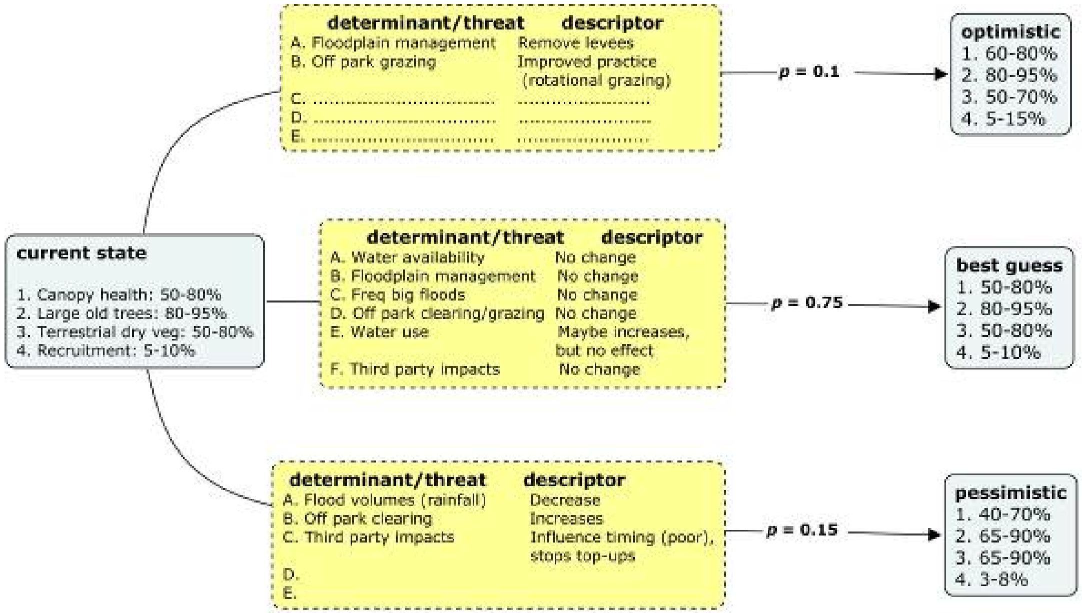
Mirela Tulbure, AWRLC, University of NSW

7.1.2. Expert judgments to establish ranges in attributes for key ecological assets under best guess, optimistic and pessimistic scenarios and the 'Business as Usual' management option.

Black-box Coolibah woodland



GROUP: Blackbox/Coolibah woodland

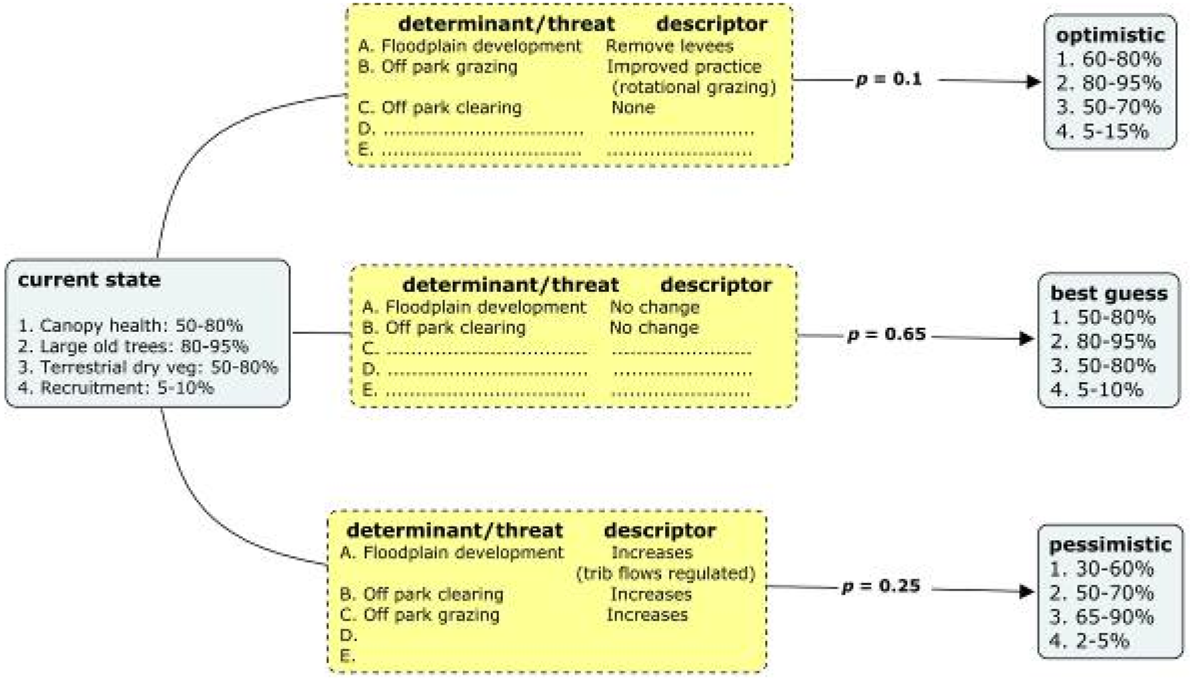
AREA: North

ASSET/VALUE: Blackbox/Coolibah woodland

SCENARIO

Climate change: Mid

Management option: Business as Usual



GROUP: Blackbox/Coolibah woodland

AREA: East

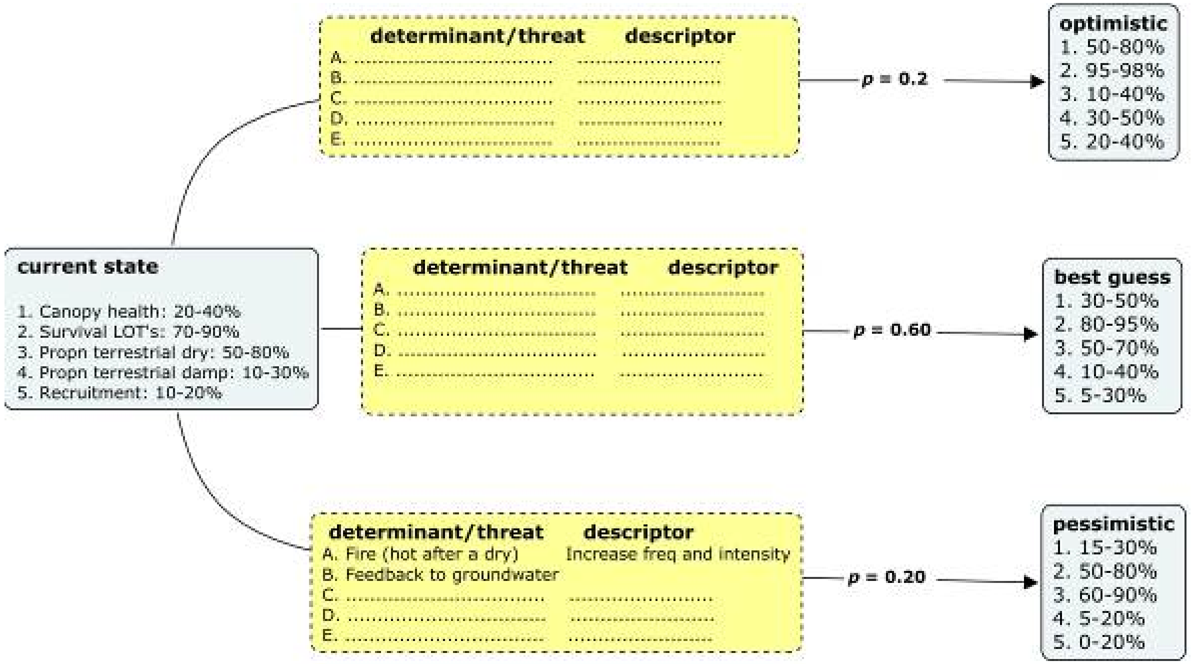
ASSET/VALUE: Blackbox/Coolibah woodland

SCENARIO

Climate change: Mid

Management option: Business as Usual

River red gum woodland



GROUP: Redgum woodland

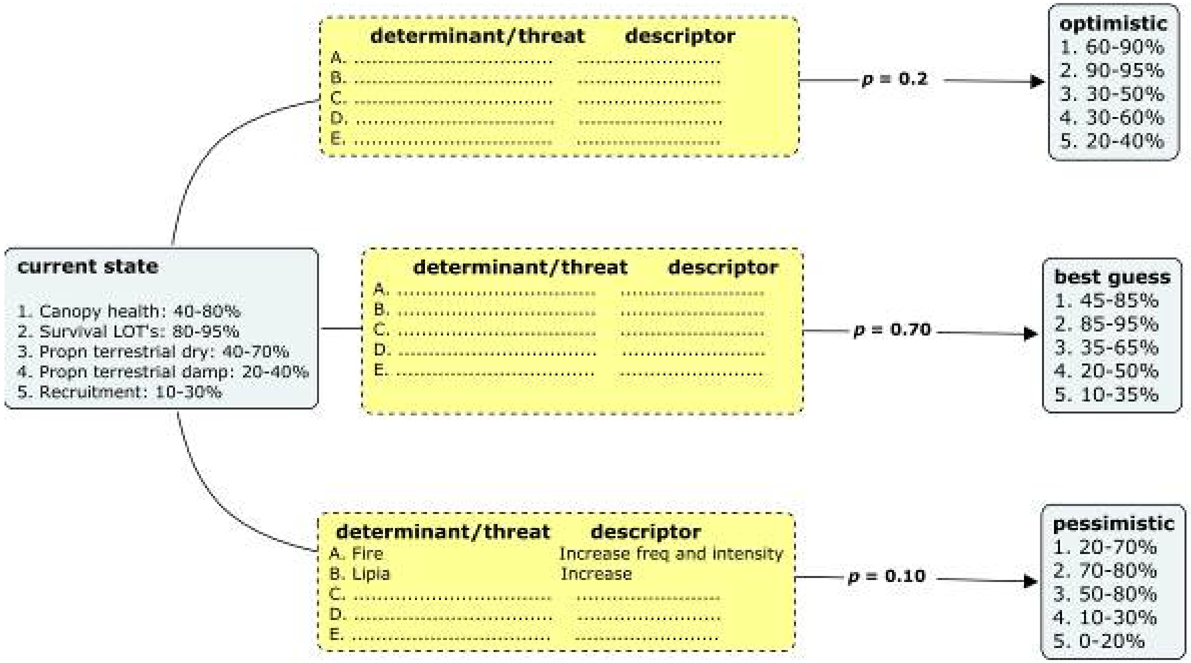
AREA: South

ASSET/VALUE: Redgum woodland

SCENARIO

Climate change: Mid

Management option: Business as Usual



GROUP: Redgum woodland

AREA: East

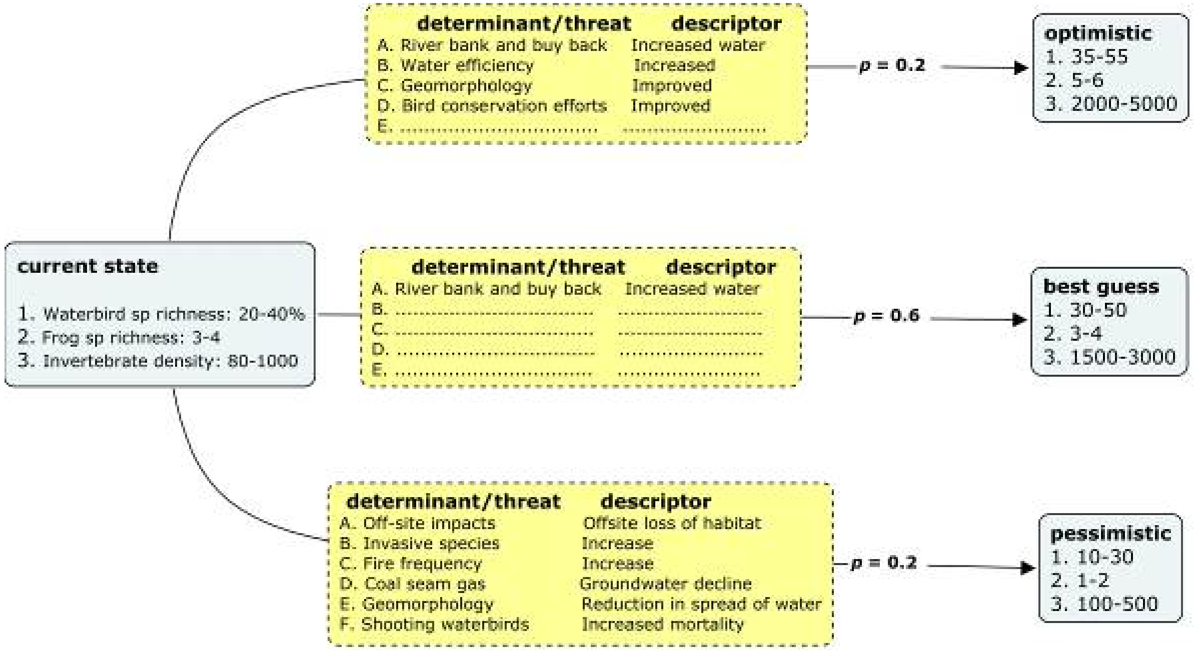
ASSET/VALUE: Redgum woodland

SCENARIO

Climate change: Mid

Management option: Business as Usual

Lagoons



GROUP: Lagoons/Birds

AREA: South

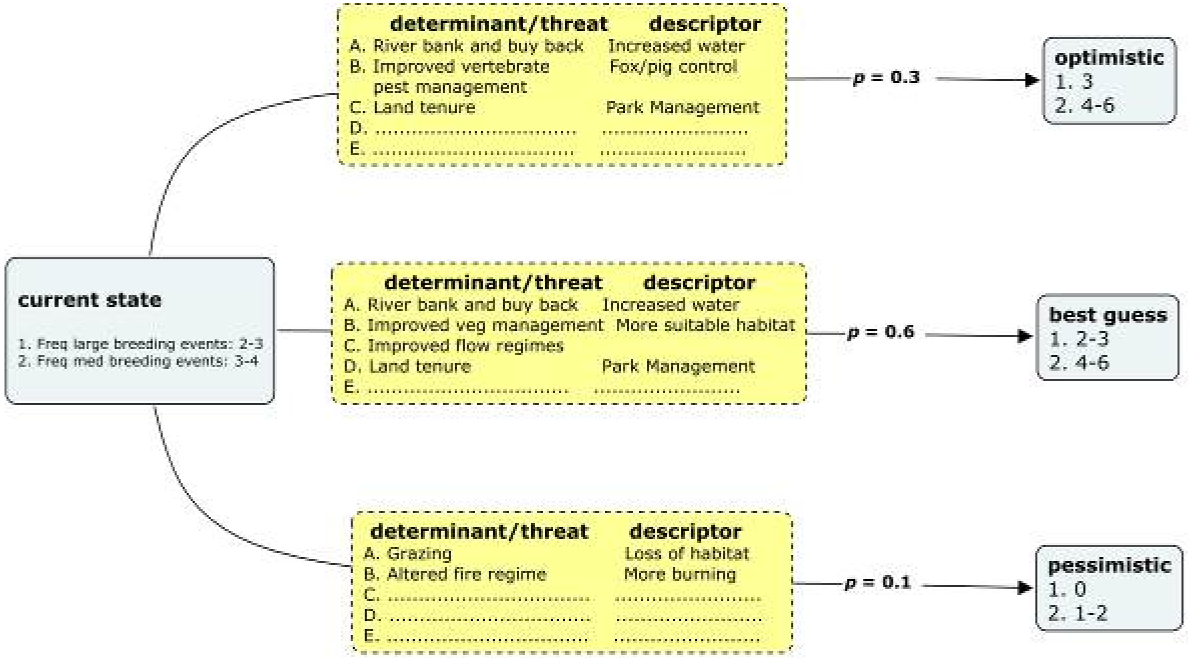
ASSET/VALUE: Lagoons South

SCENARIO

Climate change: Mid

Management option: Business as Usual

Waterbirds



GROUP: Lagoons/Birds

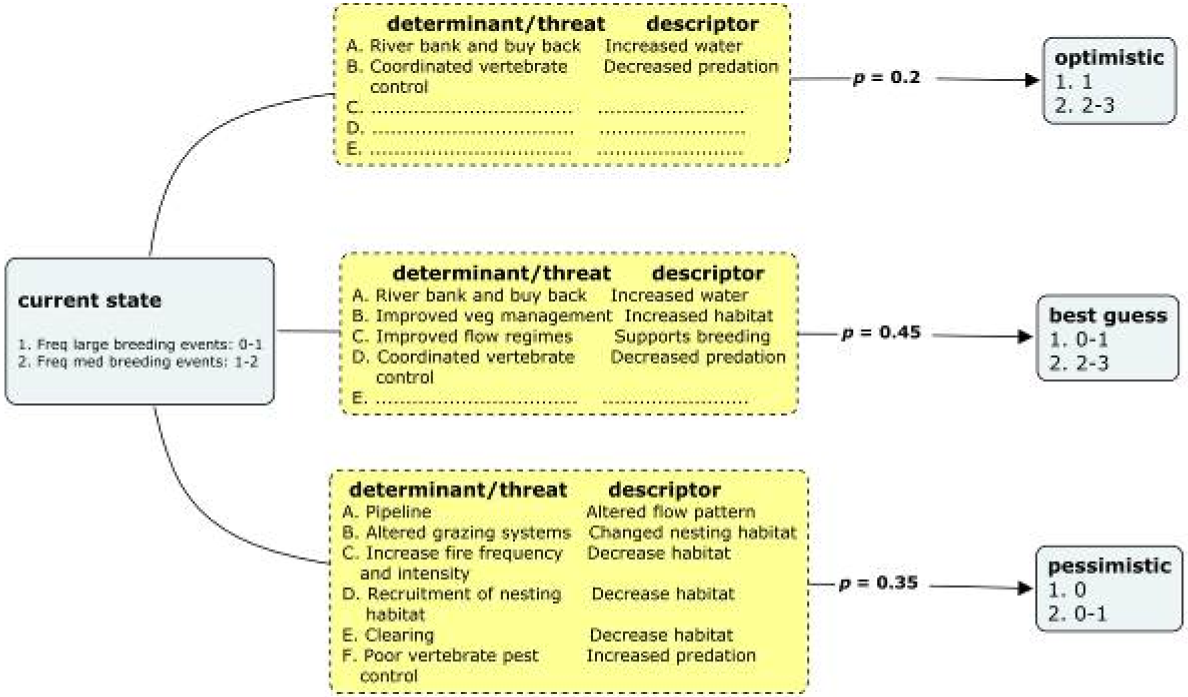
AREA: North

ASSET/VALUE: Waterbirds North

SCENARIO

Climate change: Mid

Management option: Business as Usual



GROUP: Lagoons/Birds

AREA: East

ASSET/VALUE: Waterbirds East

SCENARIO

Climate change: Mid

Management option: Business as Usual

7.1.3. Expert judgements to establish probabilities of best guess, optimistic and pessimistic attribute ranges under full suite of climate change and management scenarios

Climate change scenario	Management option	Estimate	probability						
			black box coolibah north	black box coolibah east	red gum south	red gum east	lagoons south	waterbirds north	waterbirds east
dry	Less Water	optimistic	0.00	0.00	0.00	0.00	0.05	0.10	0.10
		best guess	0.62	0.50	0.10	0.20	0.25	0.50	0.45
		pessimistic	0.38	0.50	0.90	0.80	0.70	0.40	0.45
mid	Less Water	optimistic	0.08	0.10	0.00	0.20	0.05	0.20	0.20
		best guess	0.75	0.65	0.30	0.70	0.35	0.60	0.45
		pessimistic	0.17	0.25	0.70	0.10	0.60	0.20	0.35
wet	Less Water	optimistic	0.20	0.20	0.10	0.40	0.10	0.25	0.25
		best guess	0.72	0.60	0.30	0.50	0.40	0.60	0.45
		pessimistic	0.08	0.20	0.60	0.10	0.50	0.15	0.30
dry	Business as Usual	optimistic	0.01	0.00	0.10	0.00	0.15	0.20	0.10
		best guess	0.64	0.50	0.40	0.20	0.55	0.50	0.45
		pessimistic	0.35	0.50	0.50	0.80	0.30	0.30	0.45
mid	Business as Usual	optimistic	0.10	0.10	0.20	0.20	0.20	0.30	0.20
		best guess	0.75	0.65	0.60	0.70	0.60	0.60	0.45
		pessimistic	0.15	0.25	0.20	0.10	0.20	0.10	0.35

Climate change scenario	Management option	Estimate	probability						
			black box coolibah north	**black box coolibah east**	**red gum south**	**red gum east**	**lagoons south**	**waterbirds north**	**waterbirds east**
wet	Business as Usual	optimistic	0.20	0.20	0.20	0.40	0.20	0.40	0.25
		best guess	0.72	0.60	0.70	0.50	0.60	0.55	0.45
		pessimistic	0.08	0.20	0.10	0.10	0.20	0.05	0.30
dry	More Water	optimistic	0.05	0.05	0.30	0.30	0.70	0.30	0.25
		best guess	0.80	0.85	0.60	0.60	0.20	0.60	0.55
		pessimistic	0.15	0.10	0.10	0.10	0.10	0.10	0.20
mid	More Water	optimistic	0.12	0.20	0.80	0.70	0.80	0.25	0.30
		best guess	0.78	0.75	0.20	0.20	0.15	0.70	0.60
		pessimistic	0.10	0.05	0.00	0.10	0.05	0.05	0.10
wet	More Water	optimistic	0.80	0.25	0.35	0.90	0.80	0.15	0.30
		best guess	0.15	0.73	0.64	0.10	0.20	0.80	0.65
		pessimistic	0.05	0.02	0.01	0.00	0.00	0.05	0.05

7.1.4. *Swing weighting outcomes*

	OPTIMISTIC	rank/score	BEST GUESS	score	PESSIMISTIC	score
BLACK BOX - COOLIBAH NORTH	Canopy health 60-80 Old tree survival 80 - 95 Terrestrial dry 50 - 70 Recruitment 5 - 15	7/15	Canopy health 50 -80 Old tree survival 80 -95 Terrestrial dry 50 -80 Recruitment 5 -10	10	Canopy health 40 -70 Old tree survival 65 - 90 Terrestrial dry 65 - 90 Recruitment 3 - 8	5
BLACK BOX - COOLIBAH EAST	Canopy health 60 -80 Old tree survival 80 - 95 Terrestrial dry 50 -70 Recruitment 5 -15	6/15	Canopy health 50 -80 Old tree survival 80 -95 Terrestrial dry 50 -80 Recruitment 5 -10	10	Canopy health 30 - 60 Old tree survival 50 -70 Terrestrial dry 65 - 90 Recruitment 2 - 5	0
RED GUM SOUTH	Canopy health 50 -80 Old tree survival 95 - 98 Terrestrial dry 10 -40 Terrestrial damp 30 -50 Recruitment 20 -40	1/100	Canopy health 30 -50 Old tree survival 50 -95 Terrestrial dry 50 - 70 Terrestrial damp 10 - 40 Recruitment 5 - 30	50	Canopy health 15 - 30 Old tree survival 50 - 80 Terrestrial dry 60 - 90 Terrestrial damp 5 -20 Recruitment 0 - 20	25
RED GUM EAST	Canopy health 60 -90 Old tree survival 90 -95 Terrestrial dry 30 -50 Terrestrial damp 30 -60 Recruitment 0 -40	3/80	Canopy health 45 - 85 Old tree survival 85 - 95 Terrestrial dry 35 - 65 Terrestrial damp 70 -80 Recruitment 10 - 35	65	Canopy health 20 - 70 Old tree survival 70 -80 Terrestrial dry 50 -80 Terrestrial damp 10 - 30 Recruitment 0 - 20	45
LAGOONS SOUTH	Waterbird richness 35 - 55 Frog richness 5 -6 Invertebrates 2000 - 5000	2/90	Waterbird richness 30 - 50 Frog richness 3 - 4 Invertebrates 1000 - 3000	60	Waterbird richness 10 -30 Frog richness 1-2 Invertebrates 100 -500	40
WATERBIRDS NORTH	Large breeding 3 Medium breeding 4 - 6	4/70	Large breeding 2 - 3 Medium breeding 4 - 6	60	Large breeding 0 Medium breeding 1-2	15
WATERBIRDS EAST	Large breeding 1 Medium breeding 2-3	5/40	Large breeding 0-1 Medium breeding 2-3	30	Large breeding 0 Medium breeding 0-1	10

7.2. Appendix for section 3.4, policy and legislation.

7.2.1. Species Listed as Endangered or Vulnerable in NSW Recorded in the Macquarie Marshes

Common name	Latin name	Status
Stripe-faced dunnart	Sminthopsis macroura	Vulnerable
Squirrel glider	Petaurus norfolcensis	Vulnerable
Yellow-bellied sheathtail bat	Saccolaimus flaviventris	Vulnerable
Eastern freetail bat	Mormopterus norfolkensis	Vulnerable
Little pied bat	Chalinolobus picatus	Vulnerable
Osprey	Pandion haliaetus	Vulnerable
Square-tailed kite	Lophoictinia isura	Vulnerable
Black-breasted buzzard	Hamirostra melanosternon	Vulnerable
Australian bustard	Ardeotis australis	Endangered
Australasian bittern	Botaurus poiciloptilus	Vulnerable
Black-necked stork	Ephippiorhynchus asiaticus	Endangered
Magpie goose	Anseranas semipalmata	Vulnerable
Freckled duck	Stictonetta naevosa	Vulnerable
Cotton pygmy goose	Nettapus coromandelianus	Endangered
Blue-billed duck	Oxyura australis	Vulnerable
Brolga	Grus rubicundus	Vulnerable
Bush stone-curlew	Burhinus grallarius	Endangered
Australian painted snipe	Rostratula australis	Vulnerable
Black-tailed godwit	Limosa limosa	Vulnerable
Red-backed button-quail	Turnix maculosa	Vulnerable
Major Mitchell’s cockatoo	Cacatua leadbeateri	Vulnerable
Red-tailed black-cockatoo	Calyptorhynchus banksii	Vulnerable
Glossy black-cockatoo	Calyptorhynchus lathami	Vulnerable
Turquiose parrot	Neophema pulchella	Vulnerable
Superb parrot	Polytelis swainsonii	Vulnerable
Barking owl	Ninox connivens	Vulnerable
Hooded robin	Melanodryas cucullata	Vulnerable
Grey-crowned babbler	Pomatostomus temporalis	Vulnerable
Brown treecreeper	Climacteris picumnus	Vulnerable
Painted honeyeater	Grantiella picta	Vulnerable
Black-chinned honeyeater	Melithreptus gularis gularis	Vulnerable
Diamond firetail	Stagonopleura guttata	Vulnerable
Aromatic pepper-cress	Lepidium hyssopifolia	Endangered

7.3. Appendix for section 3.6, review local knowledge

7.3.1. Oral History Interview questions

PART I: INTERVIEWEE INFORMATION

Interviewee code:

Name:

Property or organisation:

Date and time of interview:

Verbal consent: Yes No

Recorded with permission Yes No

PART II: ORIENTATION ABOUT PARTICIPANTS

1. How long have you lived in or close to the Macquarie Marshes?
2. Can you describe your property, its size and mark its location on a map?
3. How long has your family held the property?
4. What are the important parts of your property (places or processes)?
5. Have there been specific events on your property that stand out for you?
6. Which parts of the Marshes are you familiar with (mark on map)? (a base map and overlay with transparent sheets marked and ID for each interviewee)

Observations of floods

1. Can you describe what you define as a flood in the Marshes in terms of the size of the event, perhaps area covered and the duration the water remains, potentially draw this on the map?

2. Do you record when floods occurred on your property or in the broader Marshes area (maps, photographs)?

3. How much of your property flooded regularly and how has that changed to the present flooding?

4. Can you describe the flood features below from the past and how they may have changed now?

Flood feature	Past	Present
Time of year		
Duration		
Frequency		
Extent		
Flow Velocity		

5. Are there any features that you associated with floods that you no longer enjoy?

6. Have you noticed changes in the shape of the channels or the form of the floodplain…perhaps areas of sediment build up or erosion?

7. After a flood in previous years, did you find that the water depth changed very much? Did it stay this way for long?

Observations of Water quality

8. Can you describe the water when the Marshes flood?

Water quality	Past (note timing)	Present (note timing)
Colour (vary with type or timing of flood)		
Blackwater		
Smell		
Algae, green scum		
Sediment		
Fine debris		
Larger logs		

Observations of Animals

9. Have you any particular memories about fish species (e.g. Murray cod, catfish, silver perch)? Were there types of fish that you saw as a child or in the past that you no longer see?

10. Have you any particular memories about waterbird species (e.g. Ibis, ducks, egrets)? Were there types of waterbirds that you saw as a child or in the past that you no longer see?

Animals	Past (note timing of arrival and breeding, species, behaviour)	Present (note timing)
Waterbirds		
Fish		
Small fish that may be juveniles		
Carp (when arrived)		
Mosquito fish (when arrived)		
Turtles		
Snakes		
Frogs		
Invertebrates (wood lice, ants, locusts, dragonflies or aquatic ones like midges, bloodworms and snails)		
Mussels		

Observations of Plants

11. How soon after a flood have you observed water plants? Are there any particular plants that you notice (e.g. nardoo)?

12. Are the plants you observe after floods different to ones you see during dry periods?

13. Have you much experience in the growth of reedbeds and their management (e.g. fire, grazing). What was the past management of these systems?

14. I understand there used to be a substantial reedbed in the southern Marsh…why was the reed bed lost? Do you think the loss of the reed bed has affected other parts of the Marsh? Do you think the reed beds are important in the wetland?

15. There are some invasive plant species, such as noogooro burr and lippia. When did they arrive in the Marshes? Do they affect your operations? How can you control them?

16. There is evidence of dryland species (e.g. woody weeds, blue bush, roly poly) coming in to parts of the Marshes, have you noticed these changes? How much do you think the distribution of these has changed? Does this affect your operations?

17. After a flood do you notice a change in the plants that you find underneath eucalypts - e.g. does it go from grasses/pasture species to wetland species or does it stay the same? Does this differ to drier periods?

Plants	Past (note timing of germination, foliage, species)	Present (note timing)
Water plants and floating plants		
Reedbeds		
Trees and foliage		
Red gums		
Other trees		
Flowering plants (smell, changes)		
Understory plants		

Grazing productivity

18. Are you able to identify the most important parts of the Marshes for grazing and how has this changed over time? What is the productivity of frequently flooded (specify if possible) parts of the Marshes for livestock production and how does this compare to areas predominantly reliant on rainfall?

19. What grasses are critical to your livelihood – when do they best grow? Are there are plants that are good for grazing?

20. Were there particular points in time when you remember there was a lot of clearing going on? Either on your property or just generally in the area? (mark on map if possible)

21. Were then any particular times when you moved to cropping/cropped land that was previously grazed? If so, what motivated the cropping, was it the abundance of water, prices you could get for crops, etc.

Differences within the Marshes

22. Moving around the Marshes now there are striking differences between the creeks and floodplain habitats within the Marshes….for example, (pictures) in this picture of Bora Creek and the Gum Cowal the water is clear and there are many water plants…in contrast in the pictures of the Macquarie River and Bulgeregar and Monkeygar Creeks the water is more turbid and there are no water plants…were there times when these turbid creeks resembled more the Bora and Gum Cowal systems?

Water access

23. Do you use water from the marshes? What purpose do you use it for, e.g. drinking, washing clothes, swimming?

24. Has the water from the marshes ever been smelly or offensive? Was this at a particular time of year?

25. In drought, how do you cope with the lack of water, does any part of your life change? Do you use alternatives methods of water usage?

Activities associated with floods and changes to these activities

26. Are there particular activities that you associate with floods, for example do you fish, go boating, picnics?

27. Have you mustered cattle through flooded country, for example reedbeds? Can you describe what it is like mustering in the floods?

28. How often did you miss school due to floods?

29. During floods do you have more visits from friends who want to enjoy the flooded Marshes?

30. On the last occasion that you went swimming or entered the water, how deep would you say it was? What time of the year was this? Was it before or after a flood? How would you compare this event with a similar experience before the dam was built?

Sense of place and time

31. Are there areas or times that you identify with in the Marshes?

32. Are there particular plants/animals associated with these areas or times?

Climate risk

33. Do you think it likely that there are increasing risks of climate alteration in terms of changes to drought frequencies or intensities?

34. How do you think increased temperatures will affect the Marshes and your dependence on the Marshes for your livelihood?

35. What do you think are the main ways that you might be able to adapt to increased drying in the Marshes?

36. How do you think the Marshes might be able to be managed to cope with increased drying?

Final question

37. Is there anything else that you would like to add?

UNSW AUSTRALIA

Australian Government

National Water Commission

NCCARF

National Climate Change Adaptation Research Facility